ARS-BLM

SOIL-VEGETATION-HYDROLOGY

STUDY

FINAL REPORT

VOLUME I

ARS-BLM

SOIL-VEGETATION-HYDROLOGY

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FINAL REPORT

VOLUME I

Study Results, Recommendations
and Bibliography

January 1982

ARS/BLM Agreement YA-515-IA6-3

ARS-BLM SOIL-VEGETATION-HYDROLOGY STUDY

Final Report
Volume I

Preface

This report contains results of ARS-BLM cooperative research conducted in southeastern Montana from 1968 to 1981. The report is the deliverable product from the ARS to the BLM as specified in the cooperative agreement. It is presented in two volumes and an appendix:

Volume I contains project history and background; summary research results; recommendations for field application of contour furrowing; recommendations for disposition of research facilities; and a bibliography of pertinent range research publications written by scientists at the Northern Plains Soil and Water Research Center, Sidney, Montana.

Volume II is a User's Manual for the Ekalaka Rangeland Hydrology and Yield Model (ERHYM). It contains the model description; model documentation, input and output parameters, and an example of model use in which model output is compared to field measured data.

The appendix contains detailed listing of raw research data with no analysis or interpretation. Data included are: Hydrology and climate; soil chemical and physical characteristics; vegetation composition and yield; and soil water measurements by date and by soil horizon.

Copies of these may be obtained by request to:

USDA, Agricultural Research Service
Northern Plains Soil and Water Research Center
P. O. Box 1109
Sidney, Montana 59270
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Earl L. Neff
J. Ross Wight
January 1982

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INTRODUCTION

History and Objectives: On March 27, 1967, the Basic Agreement and the Service Agreement went into effect which established the Interagency Frail Lands Study (BLM Contract No. 14-11-0008-2861) as a cooperative endeavor between the Bureau of Land Management, USDI, and the Agricultural Research Service, USDA. Project objectives stated in the Service Agreement were:

1. To plan, coordinate, and conduct soil, climate, and vegetative studies to determine the potential of lands identified as frail.

2. To provide information which may be used as guidelines for making management decisions on the frail land resource areas.

3. To select representative study areas of 1 to 10 acres on which continuous streamflow records and precipitation records will be collected. Selected small watersheds will be treated by standard, accepted management practices and these practices will be evaluated by developing rainfall-runoff relationships, taking into account hydrologic characteristics such as cover type, land use, soil type, ground litter, bulk density of surface soil, and changes in soil moisture. Where possible, new management practices will be evaluated in the same way.

This cooperative agreement was in effect through FY 1974 at which time negotiations began for continuing the project with a shift in major objectives. A new Service Agreement (BLM No. YA-515-IA6-3) became effective on July 1, 1975, which established the Solonetzic Rangeland Study. Objectives were:

1. To plan, coordinate, and conduct soil, hydrologic, and vegetational studies to define major subsystems of Solonetzic rangeland systems.

2. To select representative study areas on which continuous streamflow and precipitation records will be collected. Selected small areas will be treated by various range management practices; and these practices will be evaluated by developing relationships between rainfall and runoff, rainfall and soil water, soil water and vegetation response, and runoff and sediment production taking into account characteristics such as cover type, land use, soil types, ground litter, and surface soil bulk density.

3. To develop a predictive mathematical model by applying systems analysis techniques to these data.

This agreement was amended beginning FY 1979 by changing the title to Soil-Vegetation-Hydrology Studies and by changing the objectives to read:

1. To plan, coordinate, and conduct soil, hydrologic, and vegetational studies to define major subsystems of rangelands with fine-textured soils.

2. To select representative study areas on which continuous streamflow and precipitation records will be collected. Selected small areas will be treated by various resource development practices; and these practices will be evaluated by developing relationships between rainfall and runoff, rainfall and soil water, soil water and vegetation response, and runoff and sediment production taking into account characteristics such as cover type, land use, phases of soil series, surface litter, and surface soil bulk density.

3. To develop predictive mathematical models by applying systems analysis techniques relating these data to vegetation yield and phenology; rangeland water balance; and rainfall-runoff-sediment relationships. These individual models may ultimately be combined as components of an overall rangeland management model.

Also in FY 1979, the BLM increased the level of their funding to the project to partially support a program by ARS to build, test, and evaluate a rainfall simulator as a tool for rapidly characterizing range sites. Simulator activity continued through FY 1981.

Location and Climate: Three research sites of about 40 acres each were selected in Carter County in southeastern Montana, about 15 miles south of Ekalaka, in Sections 6, 8, 9, and 10; T. 2S., R. 58 E. The general climate of the area is arid to semiarid continental with cold, relatively dry winters and warm summers. The average frost-free period is 120 days. The mean January temperature is about 20° F and the mean July temperature is about 70° F. The long-time average annual precipitation is about 12 inches of which approximately 20% occurs as snow during the cold season and 80% occurs as rain. While the annual average is 12 inches, individual year amounts are extremely variable with 5 inches and 25 inches being the minimum and maximum to be expected in this area.

Range Site Classification and Soils: Project Site 1 was on a Saline-upland range site and both Site 2 and Site 3 were on claypan range sites.

Soil on Site 1 was classified as Arsite clay which is in the family of clayey, montmorillontic, nonacid, frigid, shallow Ustic Torriorthents. This is shallow, well-drained soil formed on materials weathered from clay shale on upland plains. It is underlain by semiconsolidated shale at depths of 10 to 20 inches.

Soil on the upper half of Site 2 is Neldore clay which is in the family of clayey, montmorillontic, nonacid, frigid, shallow, Ustic Torriorthents. This is shallow, well-drained soil, formed in materials weathered from clay shale on rolling upland plains. It is underlain by semiconsolidated shale at depths of 10 to 20 inches. Included in the mapping are small areas of Arsite clay and other soils 20 to 40 inches deep over shale.

Soils on the lower half of Site 2 are Gerdrum-Absher clays. This complex consists of nearly level soils on fans and terraces. The Gerdrum soil makes up about 55 percent of the mapping unit and the Absher soil, about 35 percent. Included in mapping are about 10 percent of Vaeda soils along intermittent

drains and soils 20 to 40 inches deep over shale. Gerdrum clay loam is deep and well drained and in the family of fine, montmorillontic Borollic Natrargids. Absher silty clay is also deep and well drained and is in the family of fine, montmorillontic Borollic Natrargids. Vaeda clay is a deep, well-drained soil formed in clayey alluvium along intermittent drains on fans and terraces. It is in the family of fine, montmorillontic, nonacid, frigid Ustic Torriorthents.

Soils on Site 3 are also in the Gerdrum-Absher complex.

Vegetation: Vegetation on the claypan range sites included thickspike wheatgrass, western wheatgrass, Sandberg bluegrass, Junegrass, big sagebrush, and pricklypear cactus with blue grama, buffalograss, and clubmoss dominating small residual pedestals of coarse-textured material. On the saline-upland range site, alkali sacaton, Nuttall alkaligrass, and Nuttall saltbush were the dominant plants. A complete list of plant species found at the research site is in the appendix of this report.

Physical Layout: A total of 17 two-acre watersheds were constructed on the three research sites with five placed on Site 1 and 6 each on Sites 2 and 3. However, one watershed on Site 1 was abandoned because the flume washed out. Of the 16 remaining watersheds, 8 were treated by contour furrowing with a RM-25 furrowing machine, and 8 were left untreated. A typical watershed is shown on Fig. 1.

Site 1 (Fig. 2) is a saline upland range site with a northeasterly aspect and a general ground slope of 3 percent; Site 2 (Fig. 3) is a shallow clay range site on the upper half and a claypan range site on the lower half with a southwesterly aspect and a general ground slope of 5 percent; and Site 3 (Fig. 4) is a claypan range site with a southeasterly aspect and a general ground slope of 1 percent.

Data collection on the project was accomplished by:

1. Runoff was measured at the outlet of each watershed by a 2.5 ft. H-type flume equipped with a continuous water level recorder.

2. Precipitation was measured by a network of four normally exposed recording raingages at each site with recording pit gages operating during the warm season on both Site 1 and Site 2.

3. Sediment concentration in runoff water was measured by ten automatic pumping-type sediment samplers; six located on Site 2, and one each on a treated and an untreated watershed on Site 1 and Site 3.

4. Soil water was measured by the neutron scattering method at two stations on each watershed as well as at a number of specific investigations.

5. Foliar and basal cover were measured by the point frame method at two locations on each watershed.

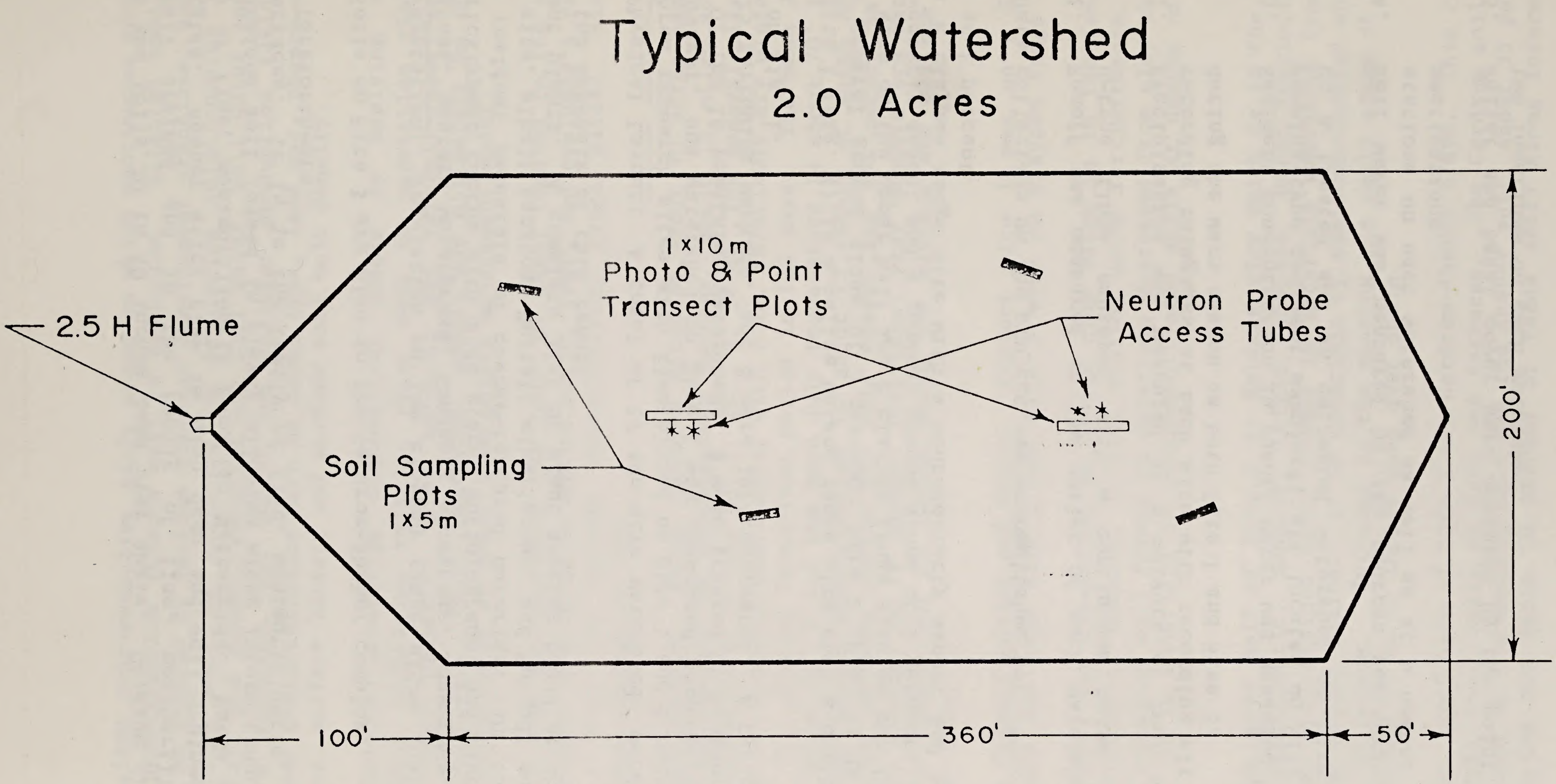

Figure 1. Typical experimental watershed at the ARS-BLM Soil-Vegetation-Hydrology Studies

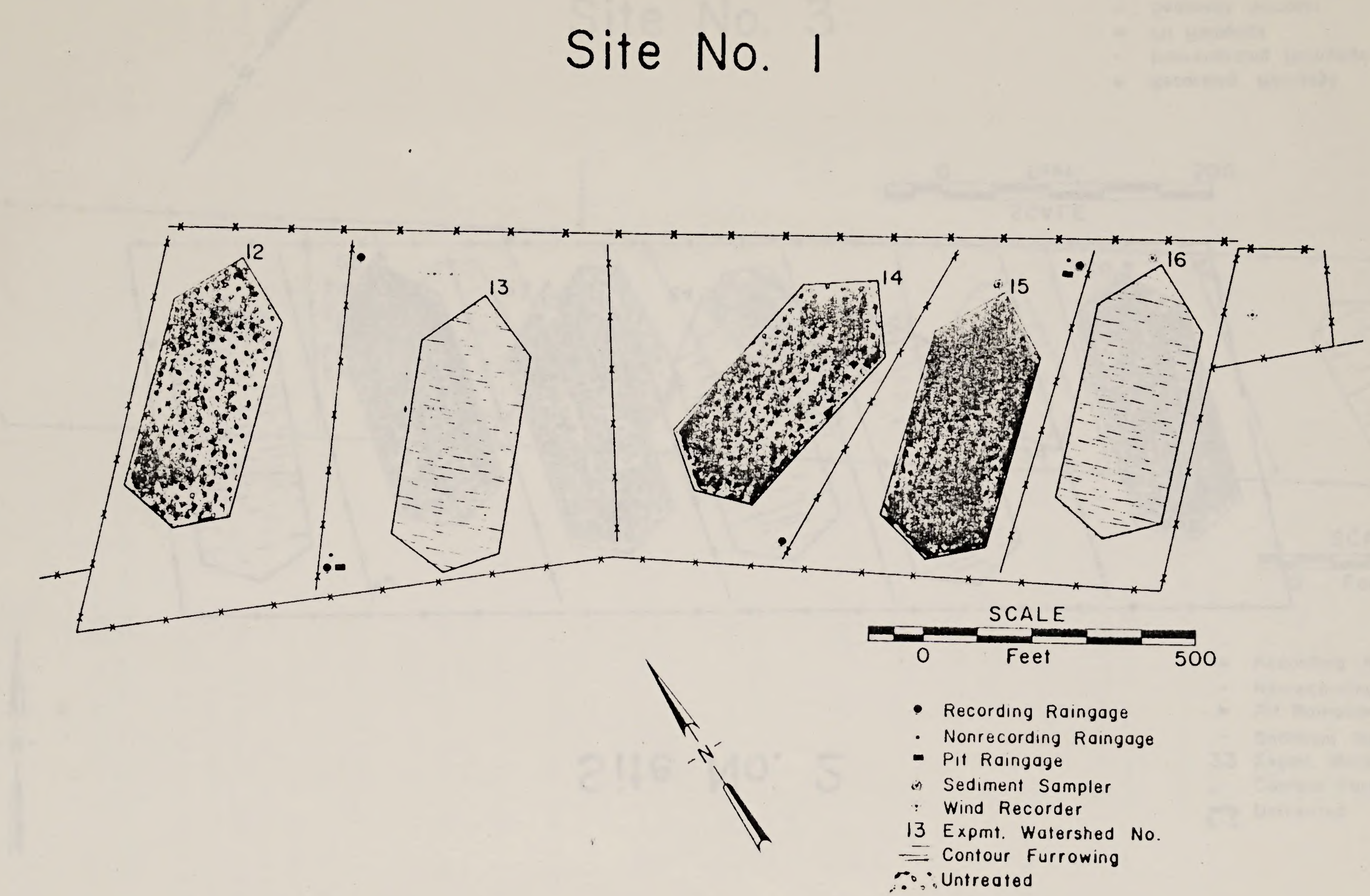

Figure 2. Site 1 at the ARS-BLM Soil-Vegetation-Hydrology Studies

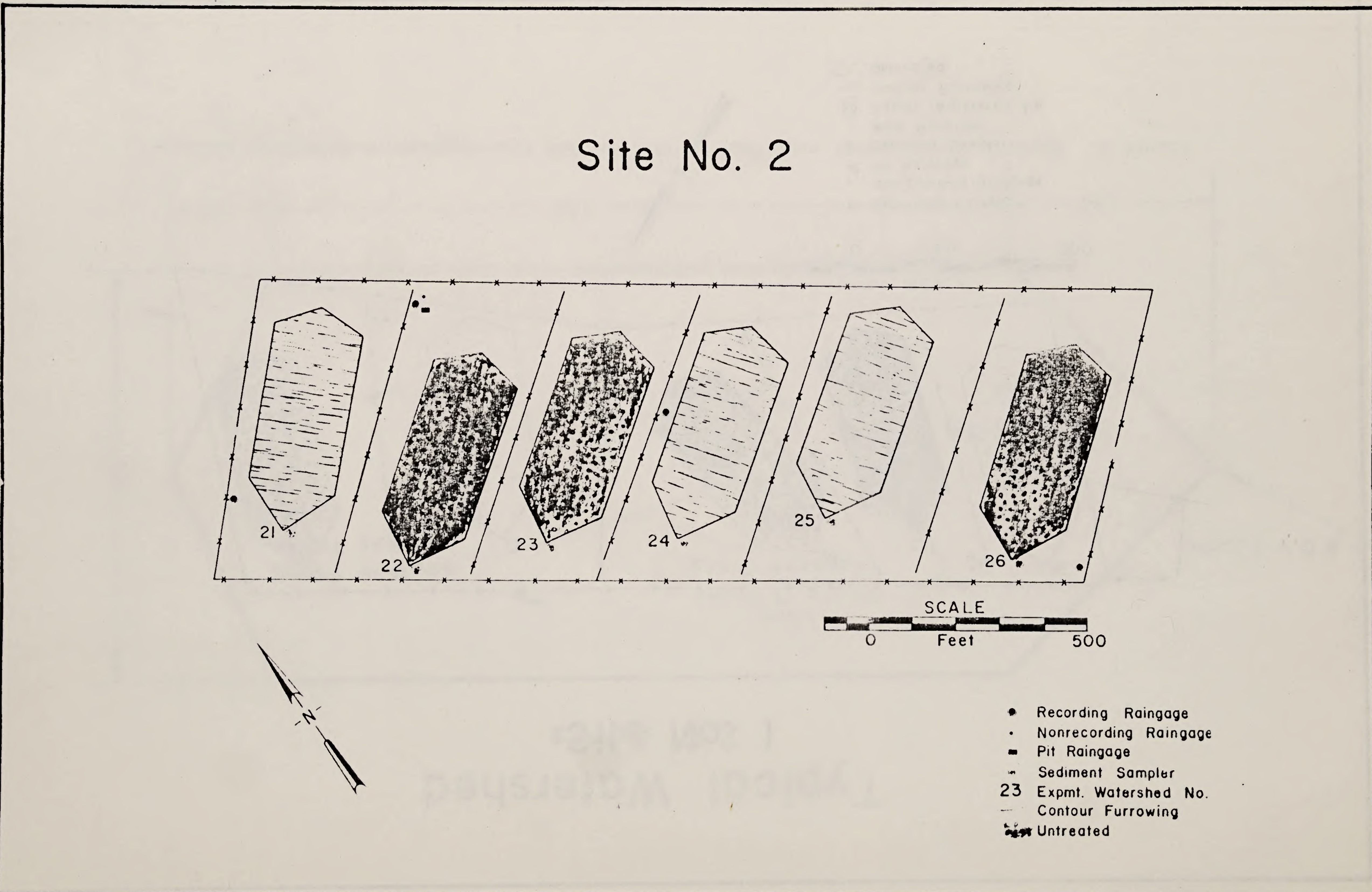

Figure 3. Site 2 at the ARS-BLM Soil-Vegetation-Hydrology Studies

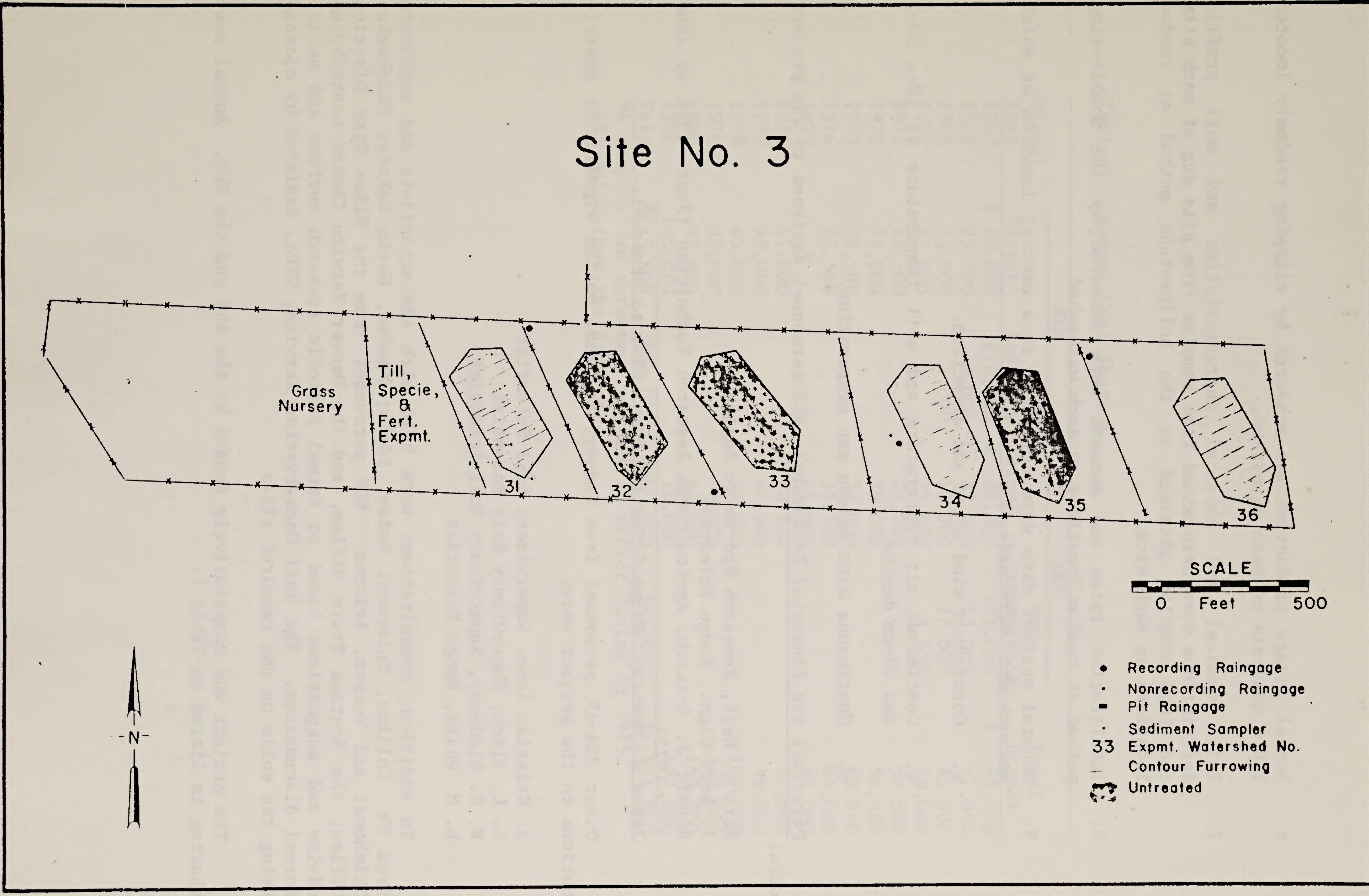

Figure 4. Site 3 at the ARS-BLM Soil-Vegetation-Hydrology Studies

6. Annual forage production was measured by clipping randomly located 1.0 m quadrats on each watershed.

7. Soil chemical and physical characteristics and soil profile descriptions were determined from samples from pits dug at each site and from samples obtained by the hollow-tube method at random locations on each site.

8. Infiltration rates and amounts were measured by the double-ring method at random locations on each watershed.

9. General weather data were collected at a central location at which measurements were made of:

   a. Continuous wind speed and direction.

   b. Continuous air temperature and soil temperature at 10-, 30-, and 90-cm depths.

   c. Continuous warm season pan evaporation.

Personnel and Financial Resources: ARS personnel assigned to the project were:

Earl L. Neff, Research Hydraulic Engineer
J. Ross Wight, Range Scientist
Ronald J. Soiseth, Agricultural Research Technician (Sept. 1968 to June 1975).
James E. Mowbray, Range Scientist (Dec. 1975 to present).

Other SEA-AR personnel from Sidney, Montana, making significant contributions to the project were:

J. Kristian Aase, Supervisory Soil Scientist
A. L. Black, Supervisory Soil Scientist
F. H. Siddoway, Supervisory Soil Scientist
L. M. White, Range Scientist

In addition, consultations were held with ARS scientists and engineers from Ft. Collins, Colorado; Boise, Idaho; Mandan, North Dakota; Chickasha, Oklahoma; and Tucson, Arizona. BLM personnel from the Miles City District Office, the Montana State Office, and the Denver Service Center contributed advice and suggestions based on formal periodic research reviews and on informal discussions. The Soil Conservation Service, USDA, assisted by classifying the soils on the research sites.

The project was cooperatively funded by the ARS and the BLM. Annual cost sharing is listed on Table 1.

Table 1. Annual Cost Sharing

Fiscal Year	BLM Direct	BLM Indirect	ARS Direct	ARS Non-expendable	Total Direct
1967	$ 20,000	$20,000	$ 25,000	$21,000	$ 45,000
1968	25,000	9,000	37,000	15,000	62,000
1969	25,000	1,000	18,000	17,000	43 000
1970	25,000		25,000	8,000	50,000
1971	28,500		25,000		53,500
1972	28,500		28,000		56,500
1973	28,500		32,000		60,500
1974	28,500		35,500		64,000
1975	*		65,000		65,000
1976	41,000		40,500		81,500
1977	48,000		51,000		99,000
1978	45,000		59,000		104,000
1979	80,000		60,000		140,000
1980	87,000		66,000		153,000
1981	105,000		72,000		177,000
Total	$615,000	$30,000	$639,000	$61,000	$1,254,000

*A cooperative agreement was not in effect during FY 1975. ARS maintained the project.

Research Results

Research results are summarized in Volume I of this report and data are listed in the report appendix. Detailed analysis, interpretation, and discussion of specific subjects can be found in publications listed in the Bibliography Section of Volume I.

Precipitation, General: Monthly and annual precipitation amounts for both the official Weather Bureau Station at Ekalaka and the Cooperative Soil-Vegetation-Hydrology Studies site (SVH) are listed in Table 2. Yearly precipitation amounts at SVH are shown on Fig. 5. The average annual precipitation at Ekalaka for the 1969-1980 study period was 115% of the long-time average. During the 12-year study period, there were 6 years in which the annual precipitation at Ekalaka was above the long-time normal, 5 years in which it was normal, and but 1 year in which it was below normal, defining normal as being within the range of plus or minus 10% of the long-time average. Assuming that the same relationships hold true at the SVH area, the long-time average annual precipitation is estimated to be about 12 inches. About 60% of the average annual precipitation at the SVH area each year occurred during 16 days in which daily rainfall was greater than 0.3 inch, 20% occurred as smaller storms in which daily rainfall was less than 0.3 inch, and 20% occurred as snow during the cold season.

Precipitation, Rainfall: Rainfall at the SVH area usually began in mid-May, reached peak of activity in June, and tapered off during the late summer and fall. About 60% of the total annual precipitation occurred during a small number of relatively large rainfall events (Table 3). On the average, there were 16 days in which daily rainfall equalled or exceeded 0.3 inch; 9 days that exceeded 0.5 inch; 2 days that exceeded 1.0 inch; and in less than 1 day per year did daily rainfall exceed 1.5 inches.

Occasional severe convective type storms with extremely high rainfall intensities occur in southeastern Montana. About 1 inch of rain fell at the SVH area between 1540 and 1545 hours on July 15, 1969. This was the maximum intensity recorded during the period of record and approached the maximum 5-minute amounts recorded at first-order Weather Bureau Stations in the hurricane paths along the Gulf and Atlantic coasts.

On Site 1 and Site 2, a normally exposed recording raingage with its orifice 40 inches above the ground surface was placed near a recording raingage placed in a pit with its orifice at ground level. These gages were used to determine the difference between the catch in normally exposed gages, and the amount of rain that actually reaches the ground surface. Pit gage catch averaged about 15% more than catch in surface gages. This difference was caused by wind disturbances created by the exposed gages and varied from zero percent during storms with low wind velocities up to 25 to 30 percent during storms with higher wind velocities. These data were used to adjust rainfall totals on a storm-by-storm basis by first calculating the ratio between the pit gage and the surface gage catch and then multiplying the catch in all other surface gages in the raingage network by this ratio. The pit gages were operated only during the rainfall season each year.

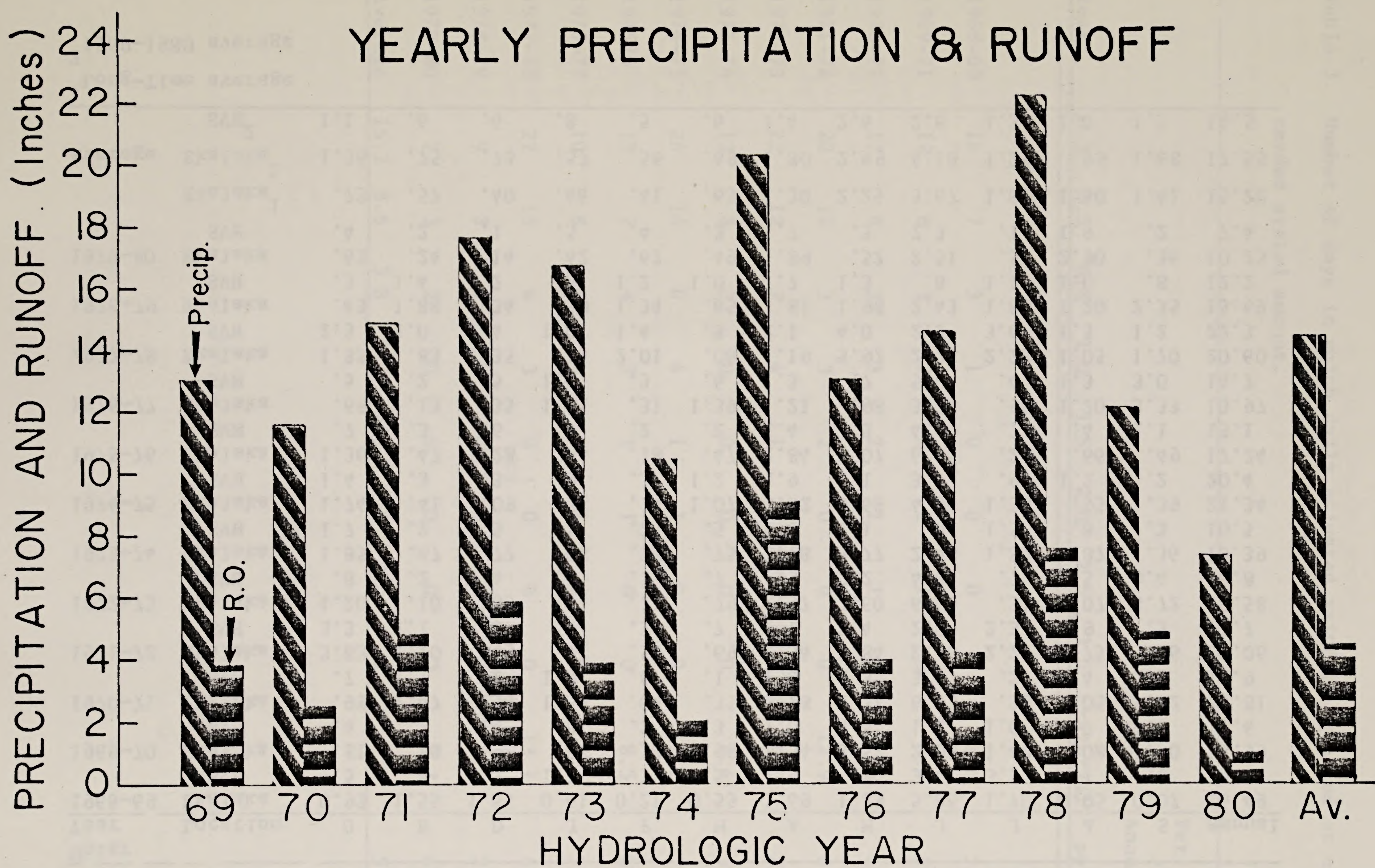

Figure 5. Yearly precipitation and runoff at the ARS-BLM Soil-Vegetation-Hydrology Studies

Table 2. Monthly and annual precipitation in inches at Ekalaka, Montana and at the Soil-Vegetation-Hydrology Research Site.

Water Year	Location	O	N	D	J	F	M	A	M	J	J	A	S	Annual
1968-69	Ekalaka	0.93	1.55	1.55	0.61	0.21	0.55	1.69	1.73	5.85	1.70	0.05	0.07	16.49
	SVH	.5	.8	1.5	1.1	.3	.5	.9	.8	3.4	3.1	.1	.0	13.0
1969-70	Ekalaka	.81	.10	.97	.62	.38	.99	1.54	3.52	2.08	1.40	.08	1.50	13.99
	SVH	.4	.2	.4	.8	.2	.3	1.0	4.4	1.2	1.0	.7	1.0	11.6
1970-71	Ekalaka	.99	1.47	.56	1.58	.64	.35	2.28	2.31	8.13	.33	.05	5.12	23.81
	SVH	.7	1.1	.2	1.0	.6	.1	1.6	2.5	3.7	.2	.4	2.8	14.9
1971-72	Ekalaka	3.83	1.10	.49	.71	.54	.69	1.34	3.84	2.78	2.23	1.75	.76	20.06
	SVH	3.3	1.1	.2	.9	.3	.7	1.1	3.4	2.0	2.3	1.9	.5	17.7
1972-73	Ekalaka	1.20	.10	.89	.11	.17	.79	2.97	2.60	6.65	.31	1.07	3.72	20.58
	SVH	.8	.2	.4	.1	.1	.7	1.9	2.2	4.8	.7	1.5	3.4	16.8
1973-74	Ekalaka	1.85	.67	.77	.04	.18	.75	2.78	3.77	2.48	1.87	.87	.36	16.39
	SVH	1.7	.2	.5	.1	.2	.5	1.8	2.1	.8	1.5	.8	.3	10.5
1974-75	Ekalaka	1.74	.41	.09	.51	.14	1.07	3.02	6.68	4.96	1.38	.95	.39	21.34
	SVH	1.4	.3	.3	.9	.3	1.2	1.9	8.1	3.7	.9	1.2	.2	20.4
1975-76	Ekalaka	1.36	.47	1.28	.54	.18	.47	2.84	2.07	6.64	.24	.66	.49	17.24
	SVH	.7	.3	.6	.3	.2	.2	2.4	1.3	4.9	.7	.4	1.1	13.1
1976-77	Ekalaka	.68	.13	.35	1.11	.31	1.39	.21	.98	3.34	.94	1.20	3.33	13.97
	SVH	.5	.2	.5	1.9	.3	.6	.3	.7	5.0	.4	1.3	3.0	14.7
1977-78	Ekalaka	1.85	.83	1.35	.15	2.01	.06	1.19	5.92	2.26	2.23	1.05	1.70	20.60
	SVH	2.3	1.0	1.4	1.0	1.4	.8	2.1	4.0	2.2	3.6	1.3	1.2	22.3
1978-79	Ekalaka	.43	1.88	.34	.39	1.34	.65	.81	1.98	2.43	1.89	1.20	2.35	15.69
	SVH	.3	1.4	1.2	.8	1.2	1.0	.7	1.3	.8	1.7	1.0	.8	12.2
1979-80	Ekalaka	.63	.24	.14	.42	.62	.49	.89	.52	2.51	.51	2.90	.36	10.23
	SVH	.4	.2	.1	.5	.4	.3	.7	.3	2.3	.1	1.9	.2	7.4
	Ekalaka[1]	.73	.57	.40	.46	.41	.63	1.30	2.25	3.67	1.89	1.50	1.41	15.22
Average	Ekalaka[2]	1.36	.75	.73	.57	.56	.69	1.80	2.99	4.18	1.25	.99	1.68	17.55
	SVH[2]	1.1	.6	.6	.8	.5	.6	1.4	2.6	2.8	1.3	1.0	1.2	14.5

[1] Long-Time average

[2] 1969-1980 average

Table 3. Number of days in which daily adjusted rainfall equalled or exceeded stated amount.

Year	0.3	0.5	0.8	1.0	1.5	2.0	2.5	3.0	Total rainfall	Pct. of Annual ppt.
1968-69	16	7	3	1	0	0	0	0	8.6	55
1969-71	11	6	3	2	2	2	1	0	8.8	61
1970-71	17	8	3	3	2	2	1	0	11.6	66
1971-72	22	12	3	3	2	0	0	0	12.9	65
1972-73	22	12	7	4	1	0	0	0	14.0	83
1973-74	13	8	2	0	0	0	0	0	6.6	57
1974-75	26	14	6	4	1	1	0	0	17.1	79
197576	13	7	4	2	1	1	0	0	8.5	60
1976-77	10	8	6	4	1	1	0	0	9.2	59
1977-78	22	15	6	3	0	0	0	0	13.1	48
1978-79	9	3	0	0	0	0	0	0	3.9	27
1979-80	7	3	2	0	0	0	0	0	3.7	48
Average	15.7	8.6	3.8	2.2	0.8	0.5	0.2	0	9.8	59

Precipitation, Snow: Snow accumulation at the SVH area usually began about December 1 each year. The year, the precipitation during the snow accumulation period, and the maximum snow accumulation for both the contour furrow treated and the untreated watersheds are listed in Table 4. Records for 1972-73, 1974-75, and 1979-80 were estimated from seasonal precipitation and snow accumulation relationships established during other years because field measurements were not taken at time of maximum snow accumulation. The seasonal precipitation listed on Table 4 is that precipitation recorded between December 1 and the beginning of snowmelt. In every year, there were some snow or combination snow-rain storms that occurred after snowmelt began. Some years, significant snow storms occurred as late as April, with occasional snow flurries extending into May and even June.

Runoff: Annual runoff from the untreated watersheds averaged about 5.7 inches from the saline-upland range site and about 4.0 inches from the claypan range sites (Table 5). Annual runoff from the contour furrowed watersheds averaged about 2.0 inches from both range sites. Seasonally, the average annual snowmelt runoff from all the untreated watersheds was about 1.7 inches and about 1.4 inches from the contour furrowed watersheds. Snowmelt runoff from the untreated watersheds accounted for about 30% of the average annual runoff from the saline-upland range site and about 40% from the claypan range sites. Snowmelt runoff from the contour furrowed watersheds accounted for about 55% and 75% of the average annual runoff from the saline-upland and the claypan range sites, respectively.

Snow drifting into the flumes and ice forming in and below the flume outlets caused problems in measuring snowmelt runoff. The flume bottoms and stilling wells were equipped with electric heating tapes, but these were inadequate to correct the problem. Therefore, snowmelt runoff from the non-furrowed watersheds was estimated by assuming it equal to the maximum snow water accumulation each year. This assumption was made because the soil was frozen during winter runoff each year, as evidenced by soil cores of concrete frost taken with the Federal Snow Sampler, and the infiltration rate of these soils, even when unfrozen, was low. Snowmelt runoff from the furrowed watersheds was assumed to equal the difference between the maximum snow water accumulation each year and the water storage capacity of the furrows. Melt of the accumulated snow pack usually began in February with the main snowmelt occurring in March or April. Most of the snowmelt occurred during a 5- to 10-day period and was characterized by relatively low flow rates and distinct diurnal fluctuations.

Infiltration: Infiltration measurements, using double-ring infiltrometers and a replicated experimental design, were made on all watersheds. Large soil cracks on the saline-upland range site confounded the measurements and negated the results. For example, one infiltrometer on an untreated watershed had an apparent initial infiltration rate of 75 in/hr. In this, and in other cases on both untreated and contour furrowed areas, soil cracks which could not be sealed caused water to flow laterally from the infiltrometer resulting in measurements which could not be interpreted.

Soil cracks on the claypan range sites created similar problems at a few locations. However, these data were not considered in the estimates of reported infiltration rates.

Table 4. Winter season precipitation and snow water equivalent in inches at time of maximum accumulation.

Year	Winter season ppt.	Site 1 Furrowed Furrow	Site 1 Furrowed Ridge	Site 1 Furrowed Average	Site 1 Unfur.	Site 2 Furrowed Furrow	Site 2 Furrowed Ridge	Site 2 Furrowed Average	Site 2 Unfur.	Site 3 Furrowed Furrow	Site 3 Furrowed Ridge	Site 3 Furrowed Average	Site 3 Unfur.
1968-69	2.6	4.8	1.6	2.9	2.4	4.6	2.4	3.2	2.6	3.0	1.4	2.0	2.3
1969-70	1.2	4.1	1.6	2.6	1.1	5.2	1.9	3.2	0.9	3.7	1.7	2.5	0.8
1970-71	1.2	4.1	1.1	2.3	1.9	5.1	1.2	2.8	1.7	5.2	1.4	2.9	1.7
1971-72	1.1	3.8	1.2	2.2	1.4	3.2	1.5	2.2	1.3	4.6	2.8	3.5	1.6
1972-73	0.5	1.5[1]	0.5[1]	0.9[1]	0.5[1]	1.5[1]	0.5[1]	0.9[1]	0.5[1]	1.5[1]	0.5[1]	0.9[1]	0.5[1]
1973-74	0.6	1.6	0.7	1.1	0.4	1.5	0.7	1.0	0.6	1.2	0.3	0.7	0.4
1974-75	1.2	4.0[1]	1.0[1]	2.5[1]	1.5[1]	4.0[1]	1.0[1]	2.5[1]	1.5[1]	4.0[1]	1.0[1]	2.5[1]	1.5[1]
1975-76	0.9	3.1	1.2	2.2	1.1	3.7	1.2	2.2	0.9	3.6	1.7	2.5	1.5
1976-77	2.4	3.0	0.8	1.7	1.2	3.5	0.6	1.7	1.2	4.2	2.2	3.1	1.1
1977-78	2.4	5.6	3.8	4.6	3.8	5.3	3.2	4.1	3.2	5.4	3.5	4.3	3.6
1978-79	2.0	3.0	1.8	2.3	2.6	3.7	1.8	2.5	2.7	4.5	2.4	3.3	2.2
1979-80	0.6	1.5[1]	0.5[1]	0.9[1]	0.5[1]	1.5[1]	0.5[1]	0.9[1]	0.5[1]	1.5[1]	0.5[1]	0.9[1]	0.5[1]
Average	1.4	3.3	1.3	2.2	1.5	3.6	1.4	2.3	1.5	3.5	1.6	2.4	1.5

[1]Estimated

Table 5. Average runoff in inches and number of days on which runoff occurred.

Year	Runoff Source	Site 1			Site 2			Site 3		
		Fur.	Unfur.	Days	Fur.	Unfur.	Days	Fur.	Unfur.	Days
1968-69										
	Snowmelt	1.40	2.50		1.70	2.60		0.50	2.30	
	Rainfall	0	1.69	13	0	1.34	11	0	0.99	10
	Total	1.40	4.19		1.70	3.94		0.50	3.29	
1969-70										
	Snowmelt	0.90	1.20		1.80	0.90		1.00	0.80	
	Rainfall	0.43	1.89	7	0.19	1.54	4	0.27	1.15	3
	Total	1.33	3.09		1.99	2.44		1.27	1.95	
1970-71										
	Snowmelt	1.00	1.90		1.40	1.70		1.60	1.70	
	Rainfall	0.22	3.90	25	0	2.83	18	0.31	2.50	11
	Total	1.22	5.80		1.40	4.53		1.91	4.20	
1971-72										
	Snowmelt	1.00	1.40		1.00	1.30		2.30	1.60	
	Rainfall	1.38	4.83	22	0	4.03	21	0.50	4.65	18
	Total	2.38	6.23		1.00	5.33		2.80	6.09	
1972-73										
	Snowmelt	0	0.50		0	0.50		0	0.50	
	Rainfall	0.98	4.94	18	0	2.82	12	0.17	2.43	11
	Total	0.98	5.44		0	3.32		0.17	2.93	
1973-74										
	Snowmelt	0	0.40		0	0.60		0	0.40	
	Rainfall	0	2.16	17	0	1.27	11	0	1.05	7
	Total	0	2.56		0	1.87		0	1.45	
1974-75										
	Snowmelt	1.50[1]	1.50[1]		1.50[1]	1.50[1]		1.50[1]	1.50[1]	
	Rainfall	4.05	8.65	25	3.03	7.62	21	4.86	6.53	17
	Total	5.55	10.15		4.53	9.12		6.36	8.03	
1975-76	Snowmelt	0.75	1.20		1.20	0.90		1.40	1.50	
	Rainfall	0.82	4.45	17	0.02	1.96	12	0.16	1.98	9
	Total	1.57	5.65		1.22	2.86		1.56	3.48	
1976-77										
	Snowmelt	0.70	1.20		0.80	1.20		2.00	1.10	
	Rainfall	2.16	4.85	8	0	1.92	7	1.10	2.23	6
	Total	2.86	6.05		0.80	3.12		3.10	3.33	
1977-78										
	Snowmelt	3.60	3.80		3.30	3.20		3.50	3.60	
	Rainfall	2.36	7.41	31	0	2.27	12	0.23	2.38	6
	Total	5.96	11.21		3.30	5.47		3.73	5.98	

Table 5. Average runoff in inches and number of days on which runoff occurred (continued).

Year	Runoff Source	Site 1 Fur.	Site 1 Unfur.	Site 1 Days	Site 2 Fur.	Site 2 Unfur.	Site 2 Days	Site 3 Fur.	Site 3 Unfur.	Site 3 Days
1978-79										
	Snowmelt	3.90	5.40		3.90	4.50		4.50	4.20	
	Rainfall	0	0.49	5	0	0.01	1	0	0	0
	Total	3.90	5.89		3.90	4.51		4.50	4.20	
1979-80	Snowmelt	0	0.60[1]		0	0.60[1]		0	0.60[1]	
	Rainfall	0.07	1.07	7	0	0.04	2	0	0	0
	Total	0.07	1.67		0	0.64		0	0.60	
Average										
	Snowmelt	1.23	1.80		1.38	1.62		1.52	1.65	
	Rainfall	1.04	3.86	16	0.27	2.30	11	0.63	2.15	8
	Total	2.27	5.66		1.65	3.92		2.15	3.80	

[1]Estimated

Third-hour infiltration rates on untreated areas on claypan range sites averaged about 0.2 in/hr and on contour furrowed areas about 0.5 in/hr. Individual measurements of third-hour rates on contour furrowed areas ranged from 0.1 in/hr to 2.0 in/hr. This illustrates both the highly variable nature of the soil and the problems associated with the double-ring infiltrometers.

Soil Water: Contour furrowing significantly increased soil water content by trapping snow and reducing runoff from snowmelt and rainfall. Figure 6 shows the effect of contour furrowing on soil water content for a below average (1977), an average (1979), and an above average (1978) soil water year. Largest differences between check and furrowed watersheds occurred in the upper two feet of the soil profile. However, on the claypan sites, small increases in soil water were evident down to the 4-foot depth. Soil water content was much more dynamic on the claypan than on the saline upland site. Due to a sparsity of transpiring vegetation, high clay content, and low infiltration rates, evapotranspiration and soil water recharge occurred at relatively slow rates on the saline upland site. As indicated in Figure 6, contour furrowing can increase overwinter recharge--i.e. the winter of 1978-79. Overwinter recharge varied considerably from year to year and was affected by both fall soil water content and overwinter precipitation. During 1969-1974, contour furrowing increased overwinter recharge an average of 0.43 and 1.54 inches (157 and 162%) on the saline upland and claypan range sites, respectively. It was also found that herbage yield was related to overwinter recharge by the function:

$$Y = 157.7X - 8.1; \quad r = 0.89$$

where Y is yield in lb/acre and X is the available spring soil water in inches in the top 2 feet of the soil profile.

Using inch-day units to reflect both the amount and duration of available soil water, furrowed and nonfurrowed watersheds are compared in Table 6. Inch-days of available water were determined by plotting the soil water content of the surface 2 feet of soil for the April 1 to July 31 growing season and measuring the area between the plot and a base line representing the lower limit of available water. Averaged over a 9-year period (1968-1976), contour furrowing increased inch-days of available water 36 and 107% on the saline upland and claypan sites, respectively. The lower limits of available soil water were determined from field data and reflected the effects of high salinity, high clay content and, to some extent, root distribution on the availability of soil water. Thus, for the saline upland site, the lower limits of water availability were relatively high. Except for 1976, inch-days of available water were closely correlated to herbage production (r = 0.82) and accounted for about 67% of yield variations.

A study was initiated in 1976 to determine the effect of furrow width on soil water and vegetation response. Contour furrows with widths of 14, 24, and 34 inches were constructed with a lister-type furrower on a claypan range site. Furrow and interfurrow areas occupied about 40 and 60%, respectively of the total area on the treated plots. Soil water was measured at approximately 2-week intervals throughout the growing season. Inch-days of available soil

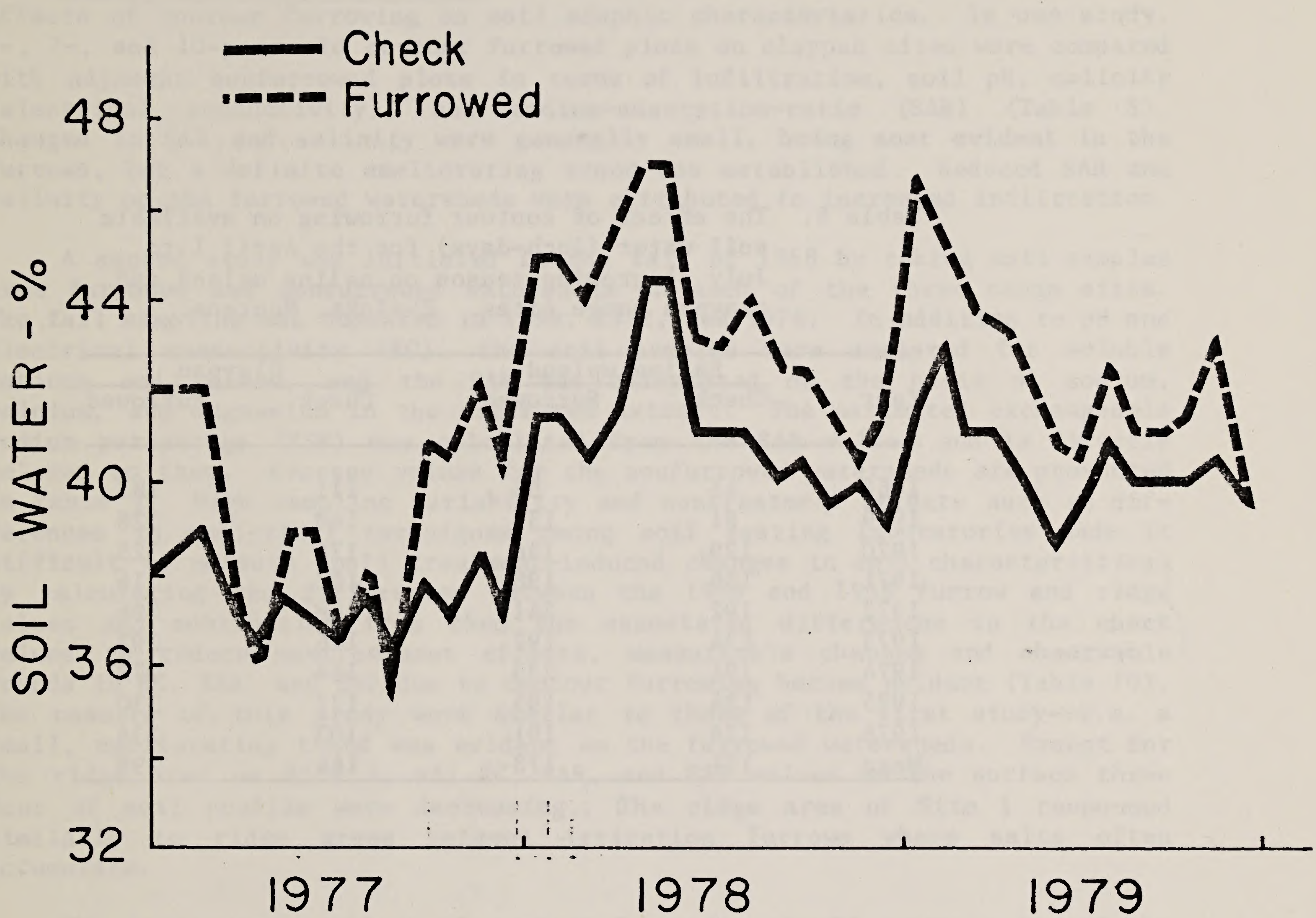

Figure 6. The effect of contour furrowing on the soil water content of the 0- to 2-foot layer soil profile of a claypan range site. Ekalaka, Montana.

Table 6. The effect of contour furrowing on available soil water (inch-days) for the April 1 to July 31 growing season on saline upland and claypan range sites. Ekalaka, Montana.

Year	Saline upland		Claypan	
	Check	Furrowed	Check	Furrowed
1968	45	56	111	187
1969	81	131	149	328
1970	129	156	176	325
1971	156	198	152	316
1972	192	241	168	396
1973	134	197	146	292
1974	191	233	154	272
1975	124	195	137	330
1976	124	191	103	236
Mean	131	178	144	298

water in the surface 2 feet of soil profile were calculated for April 1 through July 31 for 1977-1980 (Table 7). In general, available soil water increased with increased furrow width and was similar to the vegetation response which is reported under the vegetation section. These results indicate that contour furrowing increases soil water availability and that the 24-and 34-inch furrows are more effective than the narrower 14-inch furrows.

Soil Edaphic Characteristics: Two studies were conducted to evaluate the effects of contour furrowing on soil edaphic characteristics. In one study, 3-, 7-, and 10-year old contour furrowed plots on claypan sites were compared with adjacent nonfurrowed plots in terms of infiltration, soil pH, salinity (electrical conductivity), and sodium-adsorption-ratio (SAR) (Table 8). Changes in SAR and salinity were generally small, being most evident in the furrows, but a definite ameliorating trend was established. Reduced SAR and salinity on the furrowed watersheds were attributed to increased infiltration.

A second study was initiated in the fall of 1968 by taking soil samples from furrowed and nonfurrowed watersheds on each of the three range sites. The fall sampling was repeated in 1969, 1972, and 1976. In addition to pH and electrical conductivity (EC), the soil samples were analyzed for soluble cations and anions, and the SAR was calculated on the basis of sodium, calcium, and magnesium in the saturated extract. The estimated exchangeable sodium percentage (ESP) was calculated from the SAR values and is directly related to them. Average values for the nonfurrowed watersheds are presented in Table 9. High sampling variability and nontreatment effects such as differences in analytical techniques among soil testing laboratories made it difficult to measure small treatment-induced changes in soil characteristics. By calculating the differences between the 1976 and 1968 furrow and ridge values and subtracting from them the associated differences in the check values to reduce nontreatment effects, measureable changes and observable trends in EC, SAR, and ESP due to contour furrowing became evident (Table 10). The results of this study were similar to those of the first study--i.e. a small, ameliorating trend was evident on the furrowed watersheds. Except for the ridge area on Site 1, all EC, SAR, and ESP values in the surface three feet of soil profile were decreasing. The ridge area of Site 1 responded similarly to ridge areas between irrigation furrows where salts often accumulate.

The ameliorating effect of contour furrowing should continue beyond the effective life of the furrows as increased plant growth on the furrowed watersheds continue to enhance infiltration.

Applications of ammonium nitrate as N fertilizer on a claypan range site increased infiltration. Cummulated 3-hour water intake as determined by the double-ring infiltration method was 0.87 and 1.42 inches on the check and 300 lb N/acre treatments, respectively.

Runoff Water Quality and Erosion: Results are summarized in Table 11. There were only a few runoff events from the contour furrowed watersheds, so the results shown represent only a small number of samples compared to the number of samples from the untreated watersheds. In addition to the tests shown on Table 11, we also tested a few samples for nitrate nitrogen and

Table 7. Effect of contour furrow width on available soil water (inch-days) of a claypan range site. Ekalaka, Montana.

	Furrow Width (Inches)			
Year	14	24	34	Check
1977	212	269	337	98
1978	313	390	490	214
1979	213	219	245	151
1980	140	102	146	54
Mean	219	246	304	129

Table 8. Mean sodium-adsorption-ratios (SAR) and salinity values (mmhos/cm) for checks, furrows, and ridges in September 1970 (Soiseth et al., 1974)

Site	Depth interval from soil surface (inches)		SAR			EC		
	Check & Ridge	Furrow	Check	Furrow	Ridge	Check	Furrow	Ridge
1960	0-10		9.9		7.5	2.2		1.2
	10-20		14.1		10.9a	3.0		3.2
	20-30	0-10	14.0	6.4ab	13.3	5.6	1.5a	4.4
	30-40	10-20	15.3	7.3ab	15.2	5.8	2.9a	6.0
	40-50	20-30	14.6	12.9	17.2	5.7	5.7	6.6
	50-60	30-40	16.9	16.9	17.3	6.4	6.8	6.4
1963	0-10		10.5		4.5a	2.0		2.3
	10-20		15.0		8.0a	4.7		3.2a
	20-30	0-10	15.1	6.4a	14.2	6.0	3.8ab	6.2
	30-40	10-20	17.1	17.3	19.5	6.5	7.7ab	8.5a
	40-50	20-30	20.0	22.6b	21.8	6.9	9.5ab	9.0a
	50-60	30-40	20.5	23.9ab	22.7	7.8	9.8ab	8.1
1967	0-10		11.2		7.8	2.7		3.4
	10-20		17.3		9.7a	5.1		3.4a
	20-30	0-10	18.3	6.7ab	14.7a	6.6	2.8a	4.7a
	30-40	10-20	18.2	8.8ab	17.0	6.5	4.1a	6.2
	40-50	20-30	19.0	13.6ab	19.9	6.1	5.4b	7.0
	50-60	30-40	20.0	16.2a	20.0	7.2	6.5	7.2

[a]Indicates ridge significantly different (P = .10) from check at same depth intervals and/or furrow significantly from check at original depth before contour furrowing—e.g. furrow depth interval "0-10" is comparable to check depth interval "20-30."

[b]Indicates furrow significantly different (P = .10) from check at same depth interval.

Table 9. Average values of water soluble cations and anions (meq/l), EC (mmho/cm), saturated paste pH, saturation percentage (SAT %), SAR, and ESP for four 1-ft profile layers for the nonfurrowed watersheds. Ekalaka, Montana.

Site	Site 1				Site 2				Site 3			
Characteristics	0-1	1-2	2-3	3-4	0-1	1-2	2-3	3-4	0-1	1-2	2-3	3-4
Na[1]	73	85	88	89	32	50	67	81	24	27	44	48
Ca	12	12	12	11	15	16	15	14	5	6	14	14
Mg	23	26	27	27	8	14	23	29	5	4	11	13
K	1.1	1.2	1.2	1.2	0.5	0.4	0.5	0.6	0.3	0.2	0.5	0.6
CO_3[2]	0.0	0.0	0.1	0.0	1.3	1.6	1.3	1.3	0.0	0.0	0.0	0.0
HCO_3[3]	3.1	2.5	1.8	1.8	5.4	4.8	4.8	4.0	8.0	11.7	9.1	6.3
Cl[3]	0.6	0.5	0.6	0.6	0.4	0.4	0.6	0.7	0.3	0.3	0.4	0.5
NO_3[3]	0.03	0.03	0.02	0.02	0.03	0.04	0.02	0.02	0.02	0.03	0.02	0.18
SO_4[3]	129	159	171	180	80	107	143	168	74	58	109	113
EC	7.9	9.4	9.5	9.8	6.0	6.3	8.0	9.1	1.9	2.6	5.1	5.5
pH	6.3	6.1	6.1	6.0	6.7	7.0	7.2	7.3	6.8	7.6	7.7	7.7
SAT	68	114	139	156	62	76	92	107	51	64	68	71
SAR	17	19	20	21	10	13	16	18	12	12	13	14
ESP	19	21	22	22	11	14	18	20	13	14	15	16

[1]Unless otherwise indicated, the values represent the average of 4 sampling years.

[2]Measured only in 1968.

[3]Measured only in 1968 and 1969.

Table 10. EC(mmhos/cm), SAR, and ESP values for 1968, 1976, 1976 minus 1968, and normalized 1976 minus 1968 values for four 1-foot soil profile layers. Ekalaka, Montana.

	Soil depths (ft)											
	Site 1				Site 2				Site 3			
	0-1	1-2	2-3	3-4	0-1	1-2	2-3	3-4	0-1	1-2	2-3	3-4
1968												
EC-Furrow	8.9	10.4	10.8	12.0	5.0	7.3	7.9	8.2	2.0	4.5	7.0	7.3
Ridge	9.6	9.4	10.6	11.3	4.6	6.0	8.0	8.5	1.2	3.5	5.9	6.3
Check	6.7	8.3	9.2	9.1	3.5	4.8	6.0	7.4	0.8	2.3	4.6	4.9
SAR-Furrow	17.7	20.5	22.2	23.4	9.4	17.5	19.4	17.8	6.7	8.9	14.1	14.3
Ridge	19.4	20.8	22.6	22.3	13.6	16.8	19.2	20.7	7.3	9.9	12.0	13.5
Check	16.5	19.5	20.2	21.2	8.6	10.5	14.6	16.7	7.9	8.7	11.0	11.0
ESP-Furrow	18.9	22.2	23.8	24.9	11.0	19.6	21.3	20.0	7.9	10.5	16.3	16.5
Ridge	21.2	22.6	24.1	23.9	15.7	19.0	21.2	22.6	8.6	11.7	13.0	15.6
Check	18.3	21.2	22.0	22.8	9.8	11.8	16.6	18.8	9.4	10.3	13.0	13.0
1976												
EC-Furrows	10.5	11.4	11.2	12.5	5.3	7.2	9.6	10.1	3.1	3.9	5.7	6.9
Ridge	15.5	12.4	13.4	14.6	5.0	8.1	10.3	10.9	2.0	3.2	5.9	6.0
Check	10.8	11.0	10.8	11.0	11.0	7.8	10.0	11.2	3.0	3.6	6.2	6.6
SAR-Furrow	19.9	19.3	21.5	22.0	10.6	15.0	19.7	20.9	12.6	14.3	14.7	15.0
Ridge	20.8	21.4	22.8	24.2	10.7	18.3	21.5	21.4	10.3	15.0	15.2	18.9
Check	20.2	20.7	20.7	19.6	12.0	16.4	18.2	20.0	17.7	15.9	15.9	17.2
ESP-Furrow	21.6	21.2	23.3	23.8	12.3	17.2	21.7	22.8	14.2	16.2	16.3	16.9
Ridge	22.3	23.1	24.4	25.4	12.6	20.3	23.3	23.3	11.8	17.0	17.3	20.8
Check	22.1	22.6	22.6	21.6	13.8	18.5	20.4	22.1	19.9	18.2	18.1	19.4

Table 10. EC(mmhos/cm), SAR, and ESP values for 1968, 1976, 1976 minus 1968, and normalized 1976 minus 1968 values for four 1-foot soil profile layers. Ekalaka, Montana. (continued)

		Soil depths (ft)											
		Site 1				Site 2				Site 3			
		0-1	1-2	2-3	3-4	0-1	1-2	2-3	3-4	0-1	1-2	2-3	3-4
1976 minus 1968													
EC	F	1.6	1.0	0.4	0.5	0.3	-0.1	1.7	1.9	1.1	-0.6	-1.3	-0.4
	R	5.9	3.0	2.8	3.3	0.4	2.1	2.3	2.4	0.8	-0.3	0.0	-0.3
	C	4.1	2.7	1.6	1.9	7.5	3.0	4.0	3.8	2.2	1.3	1.6	1.7
SAR	F	2.2	-1.2	-0.7	-1.4	1.2	-2.5	0.3	3.1	5.9	5.4	0.6	0.7
	R	1.4	0.6	0.2	1.9	-2.9	1.5	2.3	0.7	3.0	5.1	3.2	5.4
	C	3.7	1.2	0.5	-1.6	3.4	5.9	3.6	3.3	9.8	7.2	4.9	6.2
ESP	F	2.7	-1.0	-0.5	-1.1	1.3	-2.4	0.4	2.8	6.3	5.7	0.0	0.4
	R	1.1	0.5	0.3	1.5	-3.1	1.3	2.1	0.7	3.2	5.3	4.3	5.2
	C	3.8	1.4	0.6	-1.2	4.0	6.7	3.8	3.3	10.5	7.9	5.1	6.4
1976-1968 (Normalized)													
EC	F	-2.5	-1.7	-1.2	-1.4	-7.2	-3.1	-2.3	-1.9	-1.1	-1.9	-2.9	-2.1
	R	1.8	0.3	1.2	1.4	-7.1	-0.9	-1.7	-1.4	-1.4	-1.6	-1.6	-2.0
SAR	F	-1.5	-2.4	-1.2	0.2	-2.2	-8.4	-3.3	-0.2	-3.9	-1.8	-4.3	-5.5
	R	-2.3	-0.6	-0.3	3.5	-6.3	-4.4	-1.3	-2.6	-6.8	-2.1	-1.7	-0.8
ESP	F	-1.1	-2.4	-1.1	0.1	-2.7	-9.1	-3.4	-0.5	-4.2	-2.2	-5.1	-6.0
	R	-2.7	-0.9	-0.3	2.7	-7.1	-5.4	-1.7	-2.6	-7.3	-2.6	-0.8	-1.2

[1]The 1976 minus 1968 values for the furrow and ridge are normalized by correcting them for the changes in the 1976-1968 check values--i.e. the changes in the check values (1976 minus 1968) are subtracted from all 1976 minus 1968 values. This assumes that the changes in the check values represent nontreatment effects which are then subtracted out. Negative values indicate a decrease between 1968 and 1976.

Table 11. Summary of water quality samples, soil-vegetation-hydrology studies, Ekalaka, Montana

	SALINE-UPLAND RANGE SITE					
	Unfurrowed			Contour furrowed		
	Max.	Min.	Avg.	Max.	Min.	Avg.
Elec. Conductivity, mmhos/cm	0.58	0.10	0.23	0.83	0.30	0.42
Manganese, ppm	0.07	0	0.02	0.02	0	0.01
Iron, ppm	17.3	0	3.0	0.05	0	0.02
Calcium, ppm	0.59	0.01	0.22	*	*	1.52
Magnesium, ppm	0.47	0.01	0.11	*	*	0.49
Sodium, ppm	7.5	1.1	3.3	*	*	13.4
Total dissolved solids, ppm	388	0	103	593	159	253
Sediment, ppm	3616	316	1650	3835	712	1667

	CLAYPAN RANGE SITE					
	Unfurrowed			Contour Furrowed		
	Max.	Min.	Avg.	Max.	Min.	Avg.
Elec. conductivity, mmhos/cm	0.35	0	0.06	0.13	0	0.06
Manganese, ppm	0.07	0	0.01	NR	NR	NR
Iron, ppm	9.16	0.39	1.80	NR	NR	NR
Calcium, ppm.	0.15	0	0.04	0.10	0.05	0.08
Magnesium, ppm	0.04	0	0.01	0.03	0.02	0.03
Sodium, ppm	1.52	0.45	0.88	1.76	0.78	1.30
Total dissolved solids, ppm	200	0	11	20	0	7
Sediment, ppm	1084	97	390	660	216	369

*Results from one sample

NR = No record

phosphate phosphorus. The maximum amount of nitrogen measured in any sample was 0.06 ppm and the nitrogen content of most samples was too small for our equipment to measure. The phosphorus content was less than 0.2 ppm.

Because no single ion is present in harmful amounts, the best way to describe this water quality is by total dissolved solids (TDS). Livestock water is considered "good" if the TDS is between 0 and 1,000 ppm. For the samples collected, even those with the highest TDS are well below this upper limit.

There is some indication that the salt content of runoff water increases with increasing contributing area. The TDS of runoff from the 2-acre untreated watersheds sampled in 1977 and 1978 averaged about 100 ppm; samples from Buffalo Creek, with a drainage area of about 15 square miles, taken in 1972, 1973, and 1977 averaged about 550 ppm; and a sample from Box Elder Creek, with a drainage area of about 1,000 square miles, taken in 1977, was about 850 ppm. Samples from the larger drainage areas were all taken in the spring and the concentrations probably increased during the season as the flows subsided.

Sediment concentration in runoff from the saline-upland range site averaged about 1,700 ppm from both the untreated and the contour furrowed watersheds. Concentrations from both the untreated and the contour furrowed watersheds on the claypan range site averaged about 400 ppm. These concentrations represent erosion of about 0.2 ton/acre per inch of runoff from the saline-upland range site and about 0.05 ton/acre per inch of runoff from the claypan range site. Converting these erosion rates to annual values results in the estimate that the long-term average annual sediment yield from the saline-upland range site will not exceed 0.6 ton/acre/year from the untreated watersheds and 0.3 ton/acre/year from the contour furrowed watersheds. Comparable values for the claypan range site are 0.2 and 0.1 ton/acre/year.

Conclusions reached as a result of the data are (1) the range uplands yield runoff water of high quality for livestock use, and (2) upland erosion contributes little to the downstream sediment yields.

Furrow Longevity: Furrows on the experimental watersheds were constructed with a RM-25 furrowing machine. Studies of these furrows, and others constructed with the same type machine, show that furrow water storage capacity declines exponentially (Fig. 7) with only 10% of the original water storage capacity remaining after 30 years. This decline is caused by furrows sloughing and filling in; by settling of intra-furrow dams; and by breaching of furrows and intra-furrow dams. Furrow effects on vegetation yield, infiltration, and soil chemical and physical characteristics should continue beyond this time span depending on weather and grazing management practices.

We were unable to evaluate longevity of furrows constructed with the lister-type furrowing machine. However, short-time observations indicate that they should remain effective for as long, if not longer than furrows constructed with the RM-25 machine. The shallow, broad-bottom lister-type furrows lose less storage from side sloughing and the furrow sections are separated by vegetated, more stable intrafurrow dams.

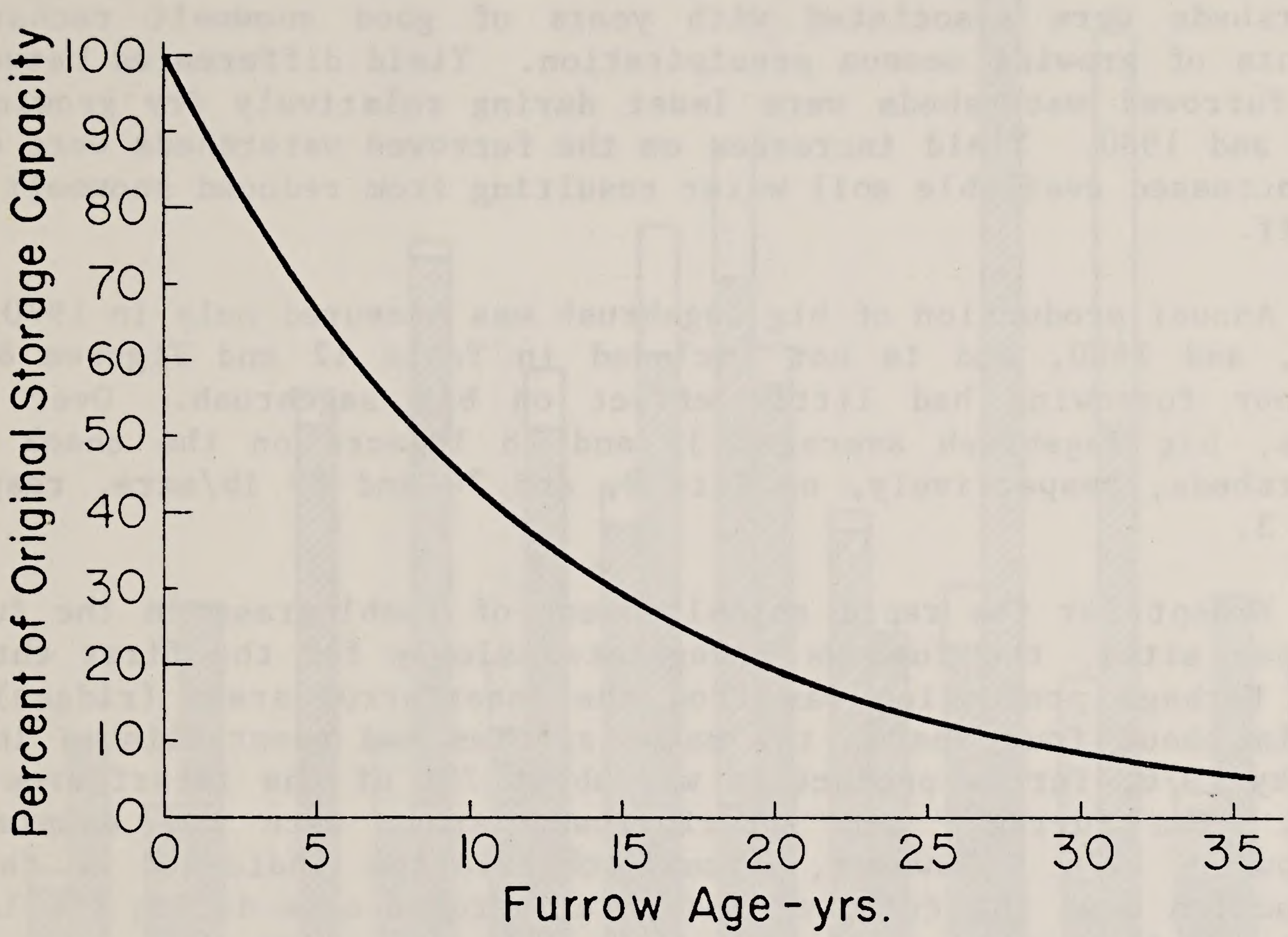

Figure 7. Age vs. water storage capacity for furrows constructed with a RM-25 furrowing machine.

Vegetation, Yield: Herbage yield data for the three study sites are presented in Table 12 and Figures 8, 9, and 10. Contour furrowing was most effective on the claypan range sites, increasing average annual yields 329 (93%) and 449 lb/acre (243%) on Sites 2 and 3, respectively, for the 1968-80 study period. On the saline-upland range site (Site 1), annual yields averaged 101 lb/acre (49%) higher on the contour furrowed watersheds than on the check watersheds. With only one replication, this difference on Site 1 was not statistically significant (p = 0.10). Except for the first year following treatment, the furrowed watersheds nearly always yielded more than the check watersheds. The biggest differences between check and furrowed watersheds were associated with years of good snowmelt recharge and high amounts of growing season precipitation. Yield differences between the check and furrowed watersheds were least during relatively dry growing seasons in 1977 and 1980. Yield increases on the furrowed watersheds were due primarily to increased available soil water resulting from reduced snowmelt and rainfall runoff.

Annual production of big sagebrush was measured only in 1970, 1971, 1972, 1974, and 1980, and is not included in Table 12 and Figures 8, 9, and 10. Contour furrowing had little effect on big sagebrush. Over the 5 sample years, big sagebrush averaged 33 and 28 lb/acre on the check and furrowed watersheds, respectively, on Site 2, and 74 and 89 lb/acre, respectively, on Site 3.

Except for the rapid establishment of tumblegrass in the furrows of the claypan sites, the furrows revegetated slowly for the first three years and most herbage production was from the interfurrow areas (ridges) (Table 13). Within about four years, the major species had reestablished in the furrows and by 1976, furrow production was about 70% of the interfurrow area production. The furrowed and interfurrowed areas were not sampled separately following 1976. However, visual observation indicated a fairly uniform production over the furrowed and interfurrowed area during the latter portion of the study period.

Vegetation, Seeded Furrows: In conjunction with a furrow-width study, four seeding treatments--no seeding, Russian wildrye, Russian wildrye and alfalfa (drylander and rambler), and alfalfa--were evaluated at three N levels--0, 75, and 150 lb N/acre. The effects of furrow width on total herbage production at the 0 and 150 lb/acre N rates are summarized for the 4-year study period in Figure 11. Without added N, yields increased almost linearly with increasing furrow width; with a single application of 150 lb N/acre, furrow width had little effect, but the furrowed plots yielded somewhat higher than the check plots.

There were no measurable yield differences among the seeded species and between seeded and nonseeded furrows. Russian wildrye and alfalfa appeared to be well adapted to the claypan range sites. The contour furrows provided a hospitable environment for establishment and subsequent growth for the seeded species. However, on Site 2 with a healthy stand of native thickspike-western wheatgrass, the furrows did not provide a yield advantage over the unseeded furrows during the first 4 years of establishment. The seeded furrows were, however, slow in developing good stands. Seeded species accounted for an

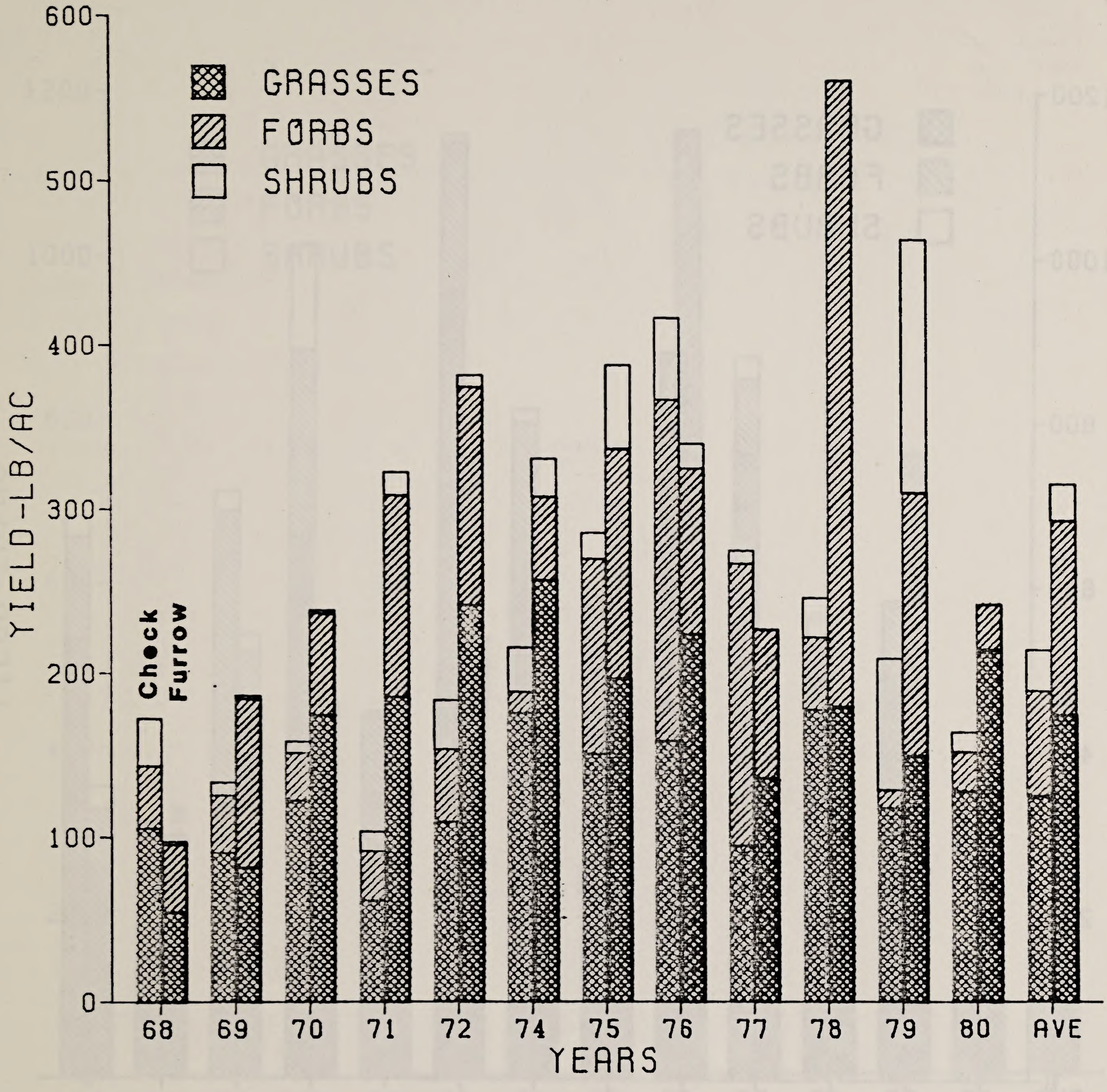

Figure 8. The effect of contour furrowing on yield of grasses, forbs, and shrubs on site 1 (a saline-upland range site), Ekalaka, Montana, 1968-1980.

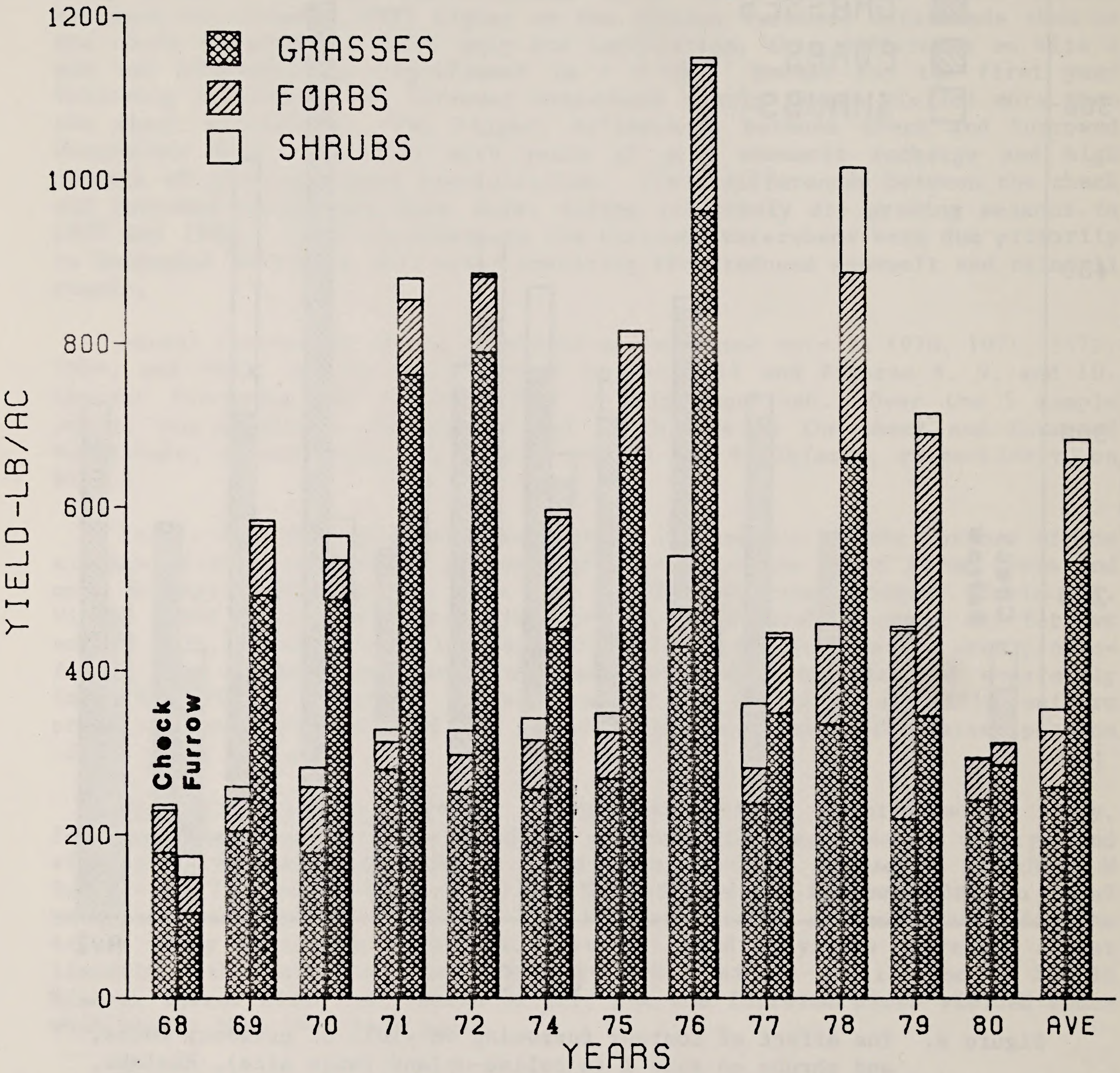

Figure 9. The effect of contour furrowing on yield of grasses, forbs, and shrubs (excluding big sagebrush) on site 2 (a claypan range site), Ekalaka, Montana, 1968-1980.

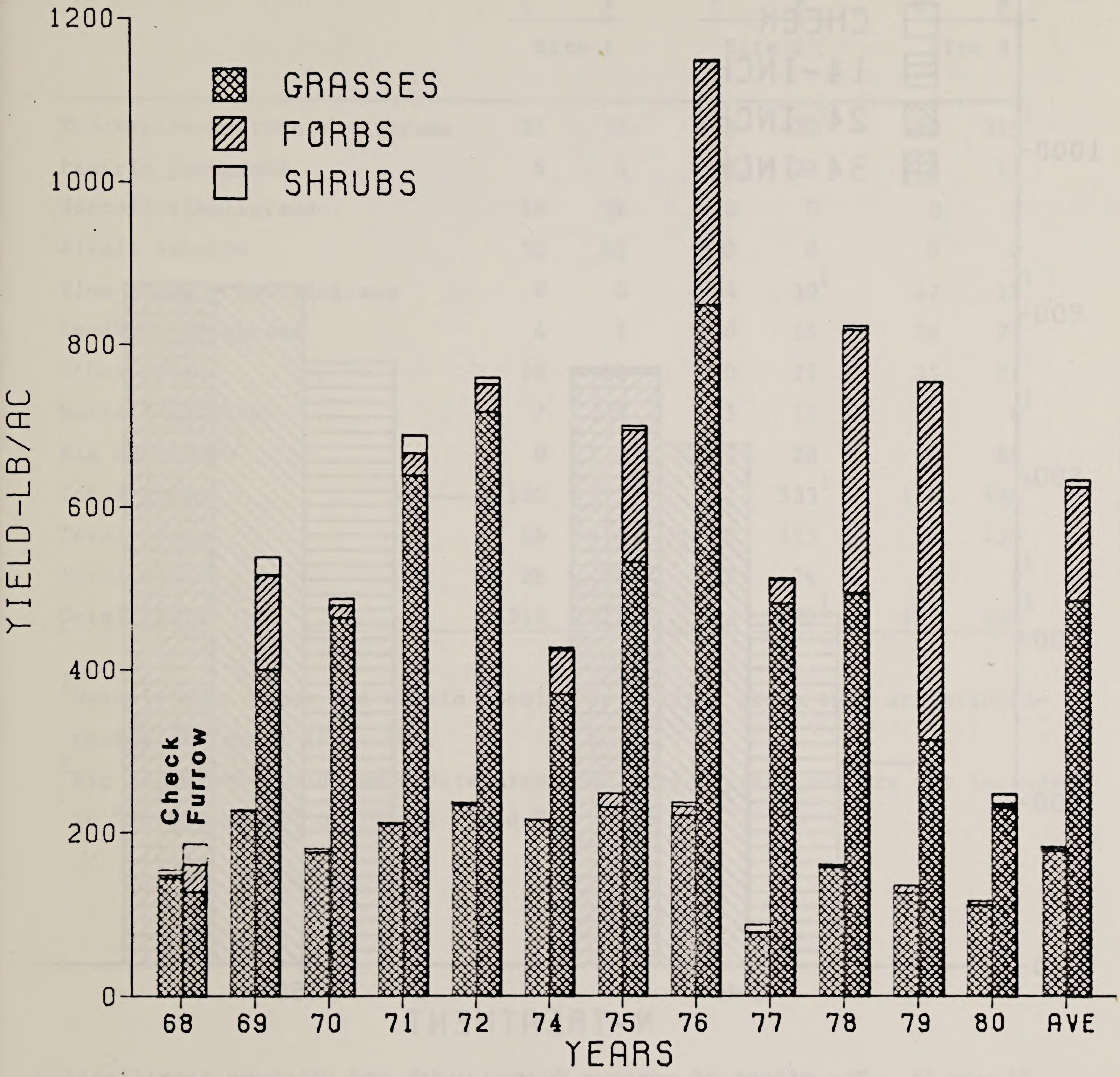

Figure 10. The effect of contour furrowing on yield of grasses, forbs, and shrubs (excluding big sagebrush) on site 3 (a claypan range site), Ekalaka, Montana, 1968-1980.

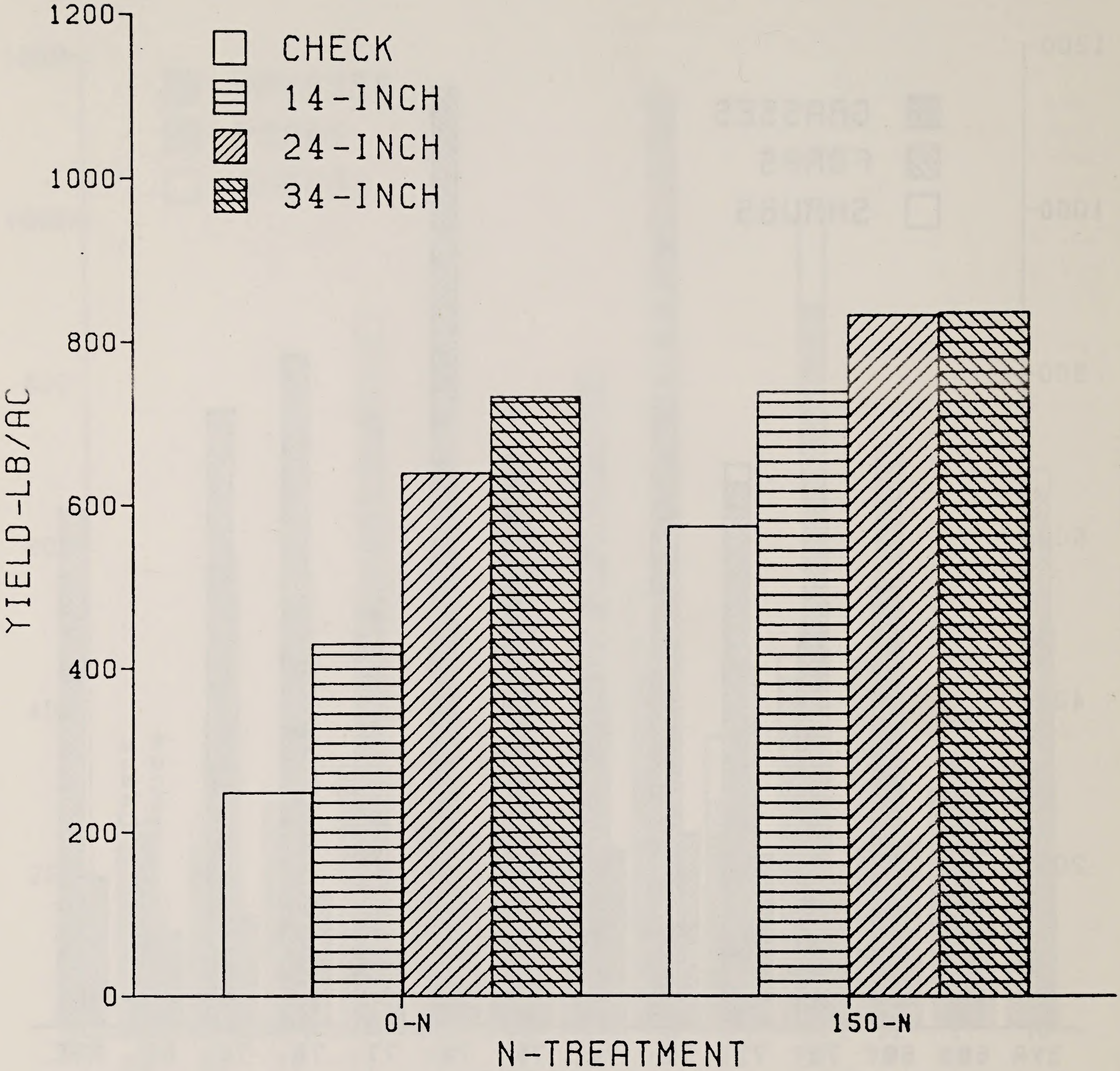

Figure 11. The effect of contour furrow width and nitrogen fertilization (0-N and 150-N) on herbage yields, Ekalaka, Montana, 1977-1980.

Table 12. Average site yields (lb/acre) of check (C) and contour furrowed (F) watersheds for 1968-1980 (excluding 1973). Ekalaka, Montana.

	Site 1 C	Site 1 F	Site 2 C	Site 2 F	Site 3 C	Site 3 F
Thickspike-western wheatgrass	31	33	123	430[1]	63	315[1]
Prairie junegrass	6	4	30	27	5	17
Nuttall alkaligrass	16	56	0	0	0	0
Alkali sacaton	52	62	0	0	0	0
Blue grama - buffalograss	0	0	54	30[1]	47	12[1]
Sandberg bluegrass	4	2	20	25	28	71
Other grass	16	18	30	21	35	71[1]
Nuttall saltbush	7	5	13	15	2	6[1]
Big sagebrush[2]	0	0	33	28	74	89
Total grass	125	175	257	533[1]	178	486[1]
Total forbs	64	118	69	125	4	139
Total shrubs	25	22	27	24	3	9[1]
Total yield	214	315	353	682[1]	185	634[1]

[1]Means within sites and within species or species group that are significantly different ($P < .10$).

[2]Big sagebrush yields were determined for only 5 years and are not included in "Total shrubs" or "Total yield."

Table 13. A comparison of herbage yield rates (lb/acre) in the furrows (F), ridges (R), and checks (C). (Wight et al., 1978)

Species	1969 F	1969 R	1969 C	1972 F	1972 R	1972 C	1976 F	1976 R	1976 C	LSD*
Saline-upland										
Nuttall alkaligrass	0	68	5	50	86	8	98	73	41	160
Alkali sacaton	0	2	59	0	78	36	70	188	89	108
Forbs	0	172	44	78	166	44	77	117	208	183
Total grass	0	138	91	162	316	110	168	260	158	86
Total yield	0	312	142	256	482	184	267	385	416	210
Claypan										
Thickspike-western wheatgrass	0	552	108	362	784	85	377	802	102	183
Foxtail	0	11	0	--	--	--	122	20	0	--
Forbs	0	168	20	86	49	24	346	278	28	165
Shrubs	0	25	9	3	9	15	0	0	36	28
Total grass	0	744	216	547	877	243	643	1215	325	184
Total yield	0	936	244	636	935	282	990	1501	388	217

*LSD (P = 0.1) valid for within-year comparisons only.

average of 11, 26, and 29% of the total herbage yield on the seeded furrows in 1978, 1979, and 1980, respectively. As the seeded stands continue to develop, they may provide a forage production advantage. Seeded furrows on a claypan range site near Miles City, Montana, proved beneficial to the overall forage production especially in terms of grazeable forage (Figure 12).

Vegetation, Response to Fertilizer: In 1973, single applications of 0, 100, 300 lb N/acre were applied to a furrowed and a nonfurrowed saline-upland range site. Yields were measured at peak standing crop for 1973-1977. The 300 lb N/acre increased the 5-year average yields from 140 to 1,000 lb/acre and 350 to 1,750 lb/acre on the nonfurrowed and furrowed plots, respectively (Figures 13 and 14). Nitrogen fertilization and contour furrowing are complementary in terms of their effects on yield. The 300 lb N/acre increased the 5-year annual yield from 140 lb/acre on the check plot (Figure 13) to 1,750 lb/acre on the furrowed plot (Figure 14). Yield response to nitrogen on the saline-upland site indicates that soil N is a critically limiting factor on this site.

Factorial combinations of 0, 50, 100, 300 lb N/acre and 0, 50, 100 lb P/acre were applied on a claypan range site in the spring of 1971. There was no yield response to P. The single application of the three N rates were effective throughout the 1971-1978 study period (Figure 15), indicating that N is also a critically limiting factor on the claypan site. The 8-year average annual yield increased from 408 lb/acre on the check plot to 1,316 lb/acre on the 300 lb N/acre plot.

In terms of nitrogen-use efficiency (units of dry matter produced per unit of applied N), N fertilization was as efficient on Sites 1 and 2 as on normal upland range sites in eastern Montana. The nitrogen-use efficiency for the 100 and 300 lb N/acre rates on site 1 was 23.2 and 14.6 on the nonfurrowed plots and 19.6 and 23.2 on the furrowed plots. On Site 2, the nitrogen-use efficiency was 17.0, 30.0, and 24.2 for the 50, 100, 300 lb N/acre treatments, respectively.

Species composition was not affected by N fertilization and remained relatively constant throughout the study periods on both Sites 1 and 2.

Vegetation, Species Adaptability: Four informal species adaptability studies were conducted during the Ekalaka study. Most evaluations were by visual observation with no statistical analyses of data. The first study was initiated in 1969 on Site 3 on a rototilled seedbed. Soil crusting was a serious problem and rototilling or similar seedbed preparation is not a recommended practice.

In 1973 and 1974, several species were seeded into the undisturbed soil on Site 1 (a saline-upland range site). There was temporary establishment of pubescent wheatgrass, Regar brome, and Garrison creeping foxtail. Crested and slender wheatgrass, Russian wildrye, and smooth bromegrass failed to establish. None of the seeded species survived to maturity. The only observed establishment of seeded species on the saline-upland range site was some slender wheatgrass in a contour furrowed plot.

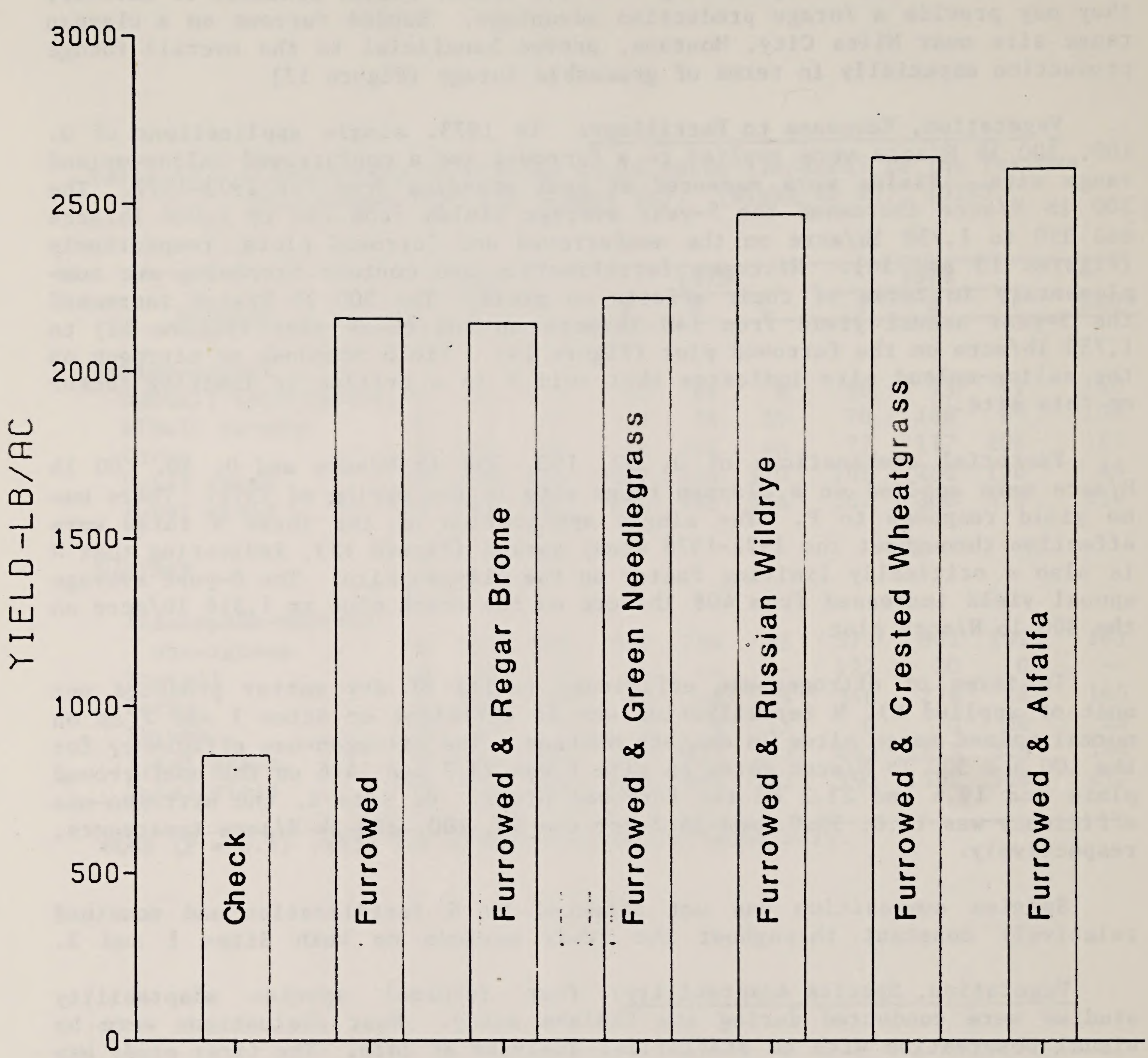

Figure 12. The effect of seeding contour furrows with native and introduced forage species on herbage yield, Miles City, Montana, 1974-1978.

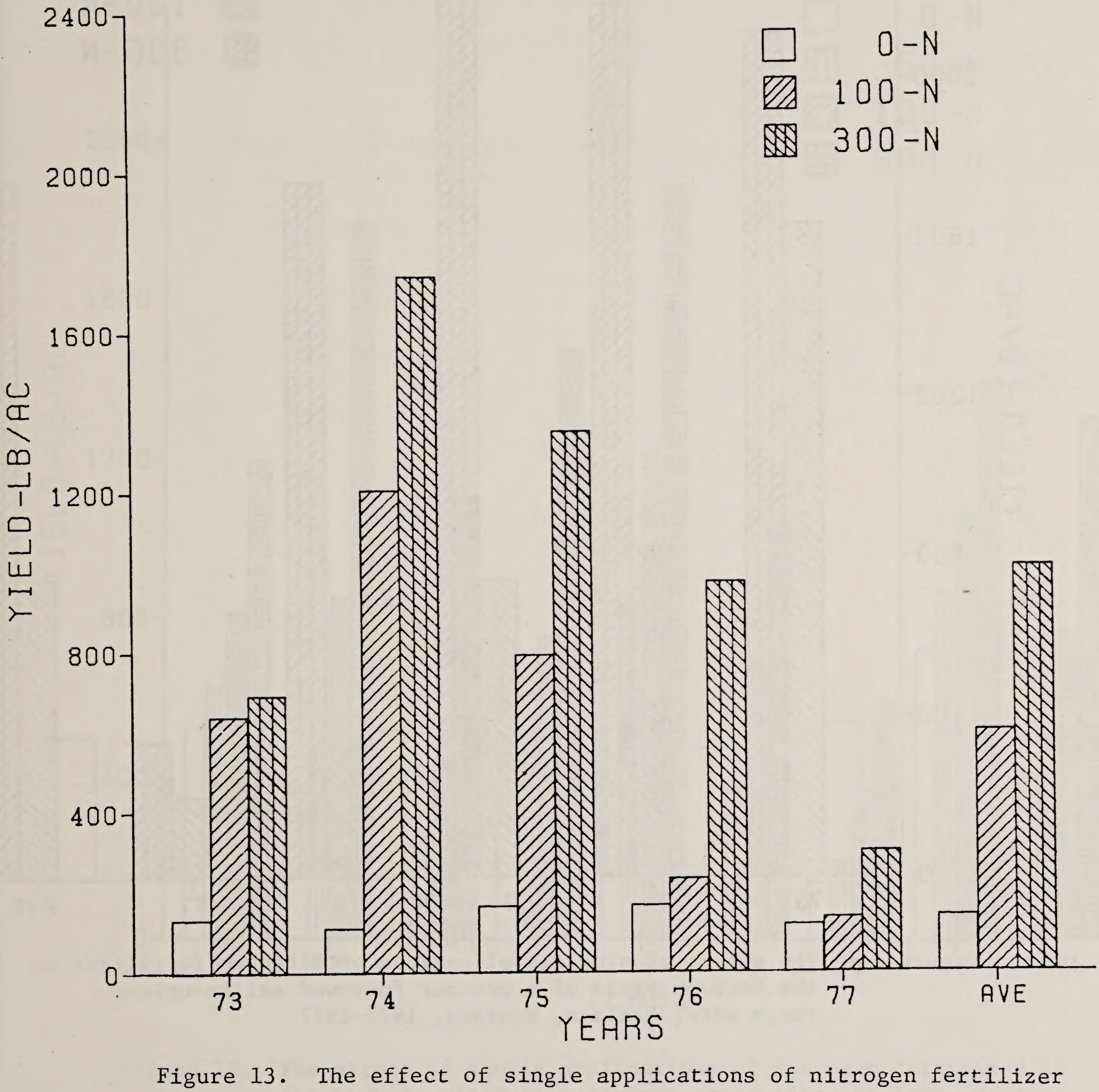

Figure 13. The effect of single applications of nitrogen fertilizer on the herbage yield of a saline-upland range site, Ekalaka, Montana, 1973-1977.

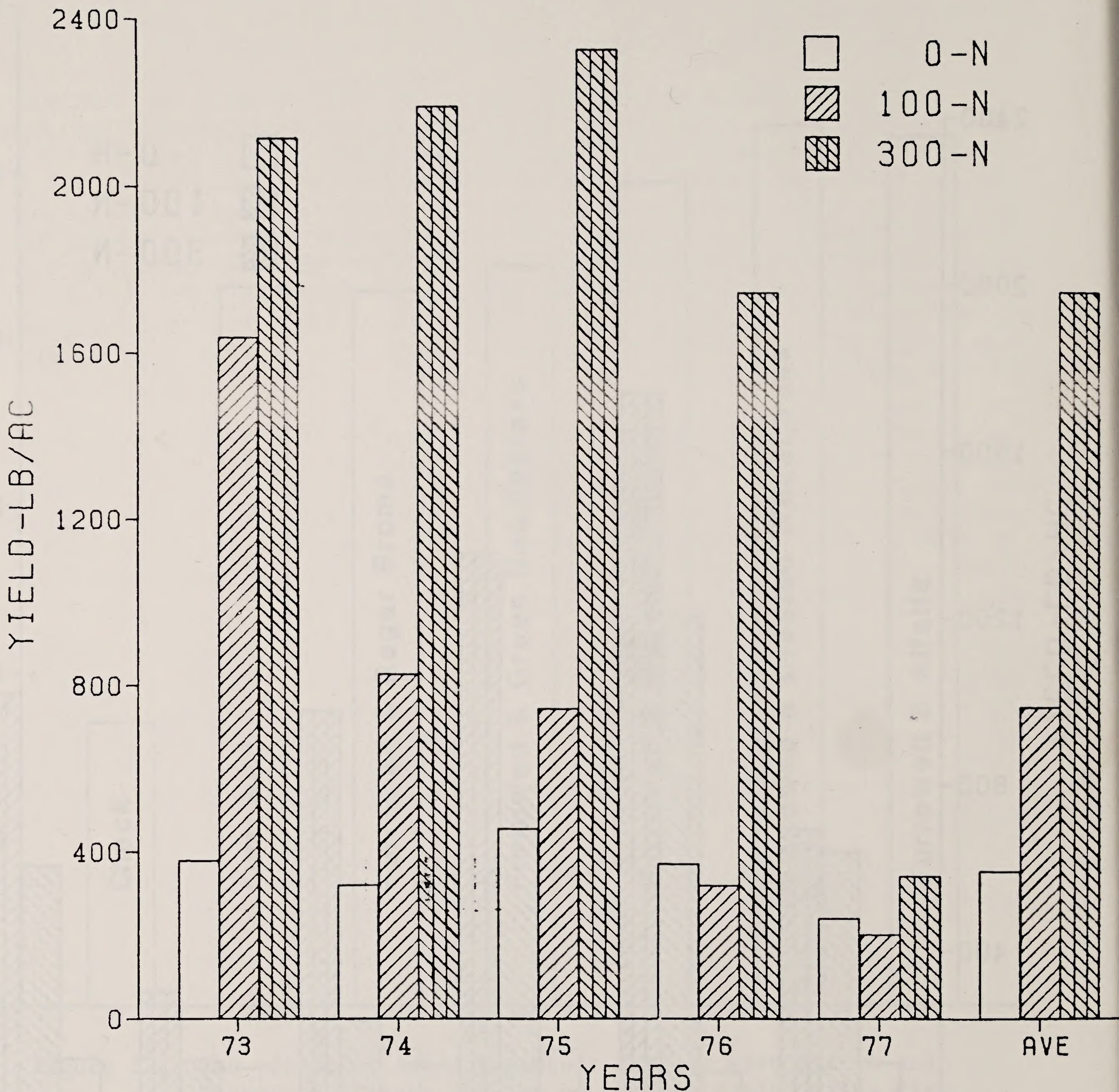

Figure 14. The effect of single applications of nitrogen fertilizer on the herbage yield of a contour furrowed saline-upland range site, Ekalaka, Montana, 1973-1977.

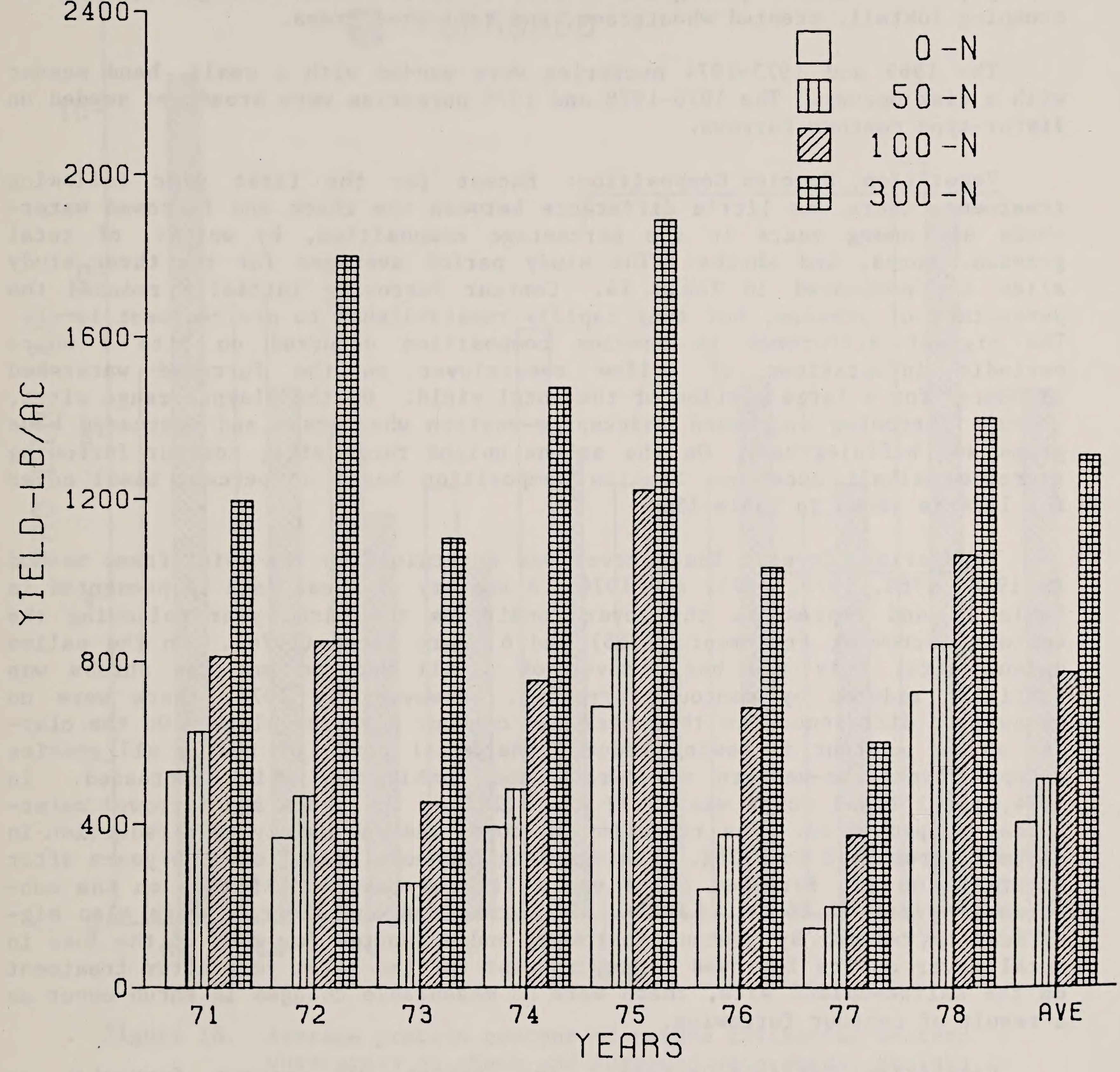

Figure 15. The effect of single applications of nitrogen fertilizer on the herbage yield of a claypan range site, Ekalaka, Montana, 1973-1977.

A third study was initiated in 1976 and 1978 in conjunction with the furrow width study, and a fourth nursery study was initiated in 1979 on Site 2. Based on these two studies, several introduced species appear well adapted to contour furrowed claypan range sites and should be considered in future seedings of similar sites. These species include: Russian wildrye, Altai wildrye, a bluebunch x quackgrass hybrid, alfalfa, smooth bromegrass, Garrison creeping foxtail, crested wheatgrass, and tall wheatgrass.

The 1969 and 1973-1974 nurseries were seeded with a small, hand seeder with a disk opener. The 1976-1978 and 1979 nurseries were broadcast seeded on lister-type contour furrows.

Vegetation, Species Composition: Except for the first year following treatment, there was little difference between the check and furrowed watersheds and among years in the percentage composition, by weight, of total grasses, forbs, and shrubs. The study period averages for the three study sites are presented in Table 14. Contour furrowing initially reduced the percentage of grasses, but they rapidly reestablished to pretreatment levels. The biggest difference in species composition occurred on Site 3 where periodic infestations of yellow sweetclover on the furrowed watershed accounted for a large portion of the total yield. On the claypan range sites, contour furrowing increased thickspike-western wheatgrass and decreased blue grama and buffalograss. On the saline upland range site, contour furrowing increased alkali sacaton. Species composition based on percent basal cover for 1974 is shown in Table 15.

Vegetation, Cover: Basal cover was determined by the point-frame method in 1968, 1969, 1970, 1971, and 1974. A summary of these data is presented in Table 15 and represents the cover conditions the first year following the contour furrowing treatment (1968) and 6 years later (1974). On the saline upland site, only the basal cover of alkali sacaton and the shrubs was initially reduced by contour furrowing. However, by 1974, there were no measurable differences in the check and contour furrowed plots. On the claypan sites, contour furrowing reduced the basal cover of nearly all species except thickspike-western wheatgrass and tumblegrass which increased. In 1974, total basal cover was 15.72 and 4.28% on the check and furrowed watersheds, respectively. The reduction in cover was due mainly to a reduction in clubmoss from 9.38 to 0.36%. Disregarding clubmoss, basal cover 6 years after treatment on the furrowed plots was still only about half that on the nonfurrowed plots (3.86 vs. 6.35%). Bluegrama and buffalograss were also significantly reduced by contour furrowing and accounted for much of the loss in total cover on the furrowed plots. Except for the first year after treatment on the saline-upland site, there were no measurable changes in shrub cover as a result of contour furrowing.

Vegetation, Nutrient Content: The effect of contour furrowing on nutrient content was determined by measuring the crude protein and phosphorus (P) content of thickspike-western wheatgrass harvested from furrowed and nonfurrowed watersheds during 1968-1977. Plants were harvested near peak standing crop. The protein content was higher on the furrowed watersheds than on the nonfurrowed watersheds the first year following treatment, and then dropped below the check level until 1975, 8 years following the furrowing treatment (Figure 16). It appears that the temporary fertility effect that

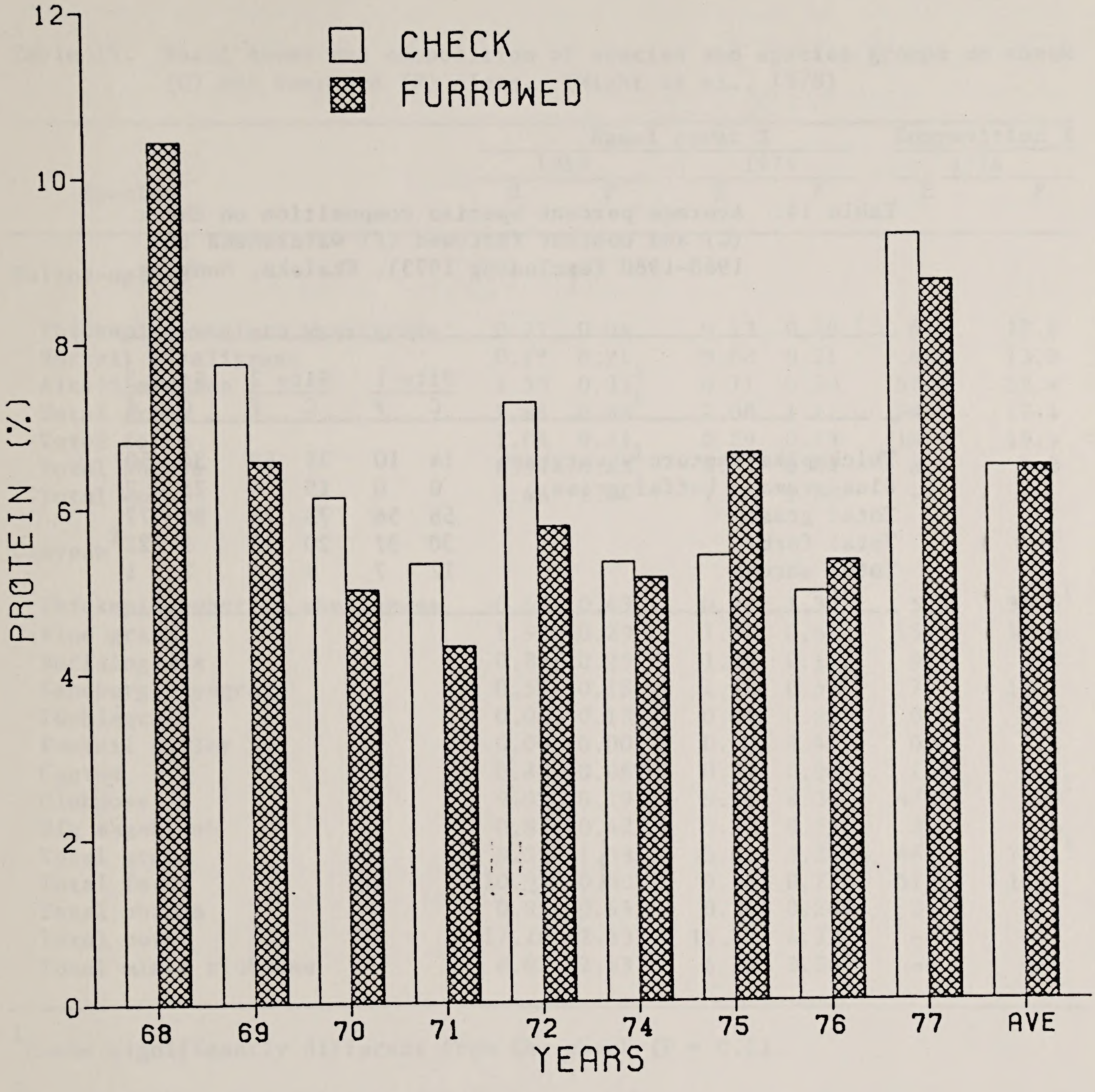

Figure 16. Average protein content of mature thickspike-western wheatgrass on check and furrowed watersheds, Ekalaka, Montana, 1968-1977.

Table 14. Average percent species composition on check (C) and contour furrowed (F) watersheds for 1968-1980 (excluding 1973), Ekalaka, Montana.

	Site 1		Site 2		Site 3	
	C	F	C	F	C	F
Thickspike-western wheatgrass	14	10	35	63	34	50
Blue grama - buffalograss	0	0	15	4	25	2
Total grass	58	56	73	78	95	77
Total forbs	30	37	20	18	2	22
Total shrubs	12	7	8	4	2	1

Table 15. Basal cover and composition of species and species groups on check (C) and furrowed (F) plots. (Wight et al., 1978)

Species	Basal cover %				Composition %	
	1968		1974		1974	
	C	F	C	F	C	F
Saline-upland						
Thickspike-western wheatgrass	0.21	0.04	0.13	0.29	6.5	18.6
Nuttall alkaligrass	0.17	0.21	0.08	0.21	4.4	13.8
Alkali sacaton	1.50	0.33[1]	0.71	0.50	52.0	32.4
Total grass	1.88	0.58[1]	1.08	1.17	74.9	77.1
Total forbs	1.04	0.21	0.29	0.29	18.6	19.5
Total shrubs	0.54	0.25[1]	0.13	0.04	6.5	3.3
Total cover	3.46	1.04[1]	1.50	1.50	--	--
Claypan[2]						
Thickspike-western wheatgrass	0.67	0.43	0.71	1.39[1]	5.4	35.5[1]
Blue grama	1.92	0.29[1]	1.82	0.61	15.8	14.6
Buffalograss	0.83	0.25[1]	1.29	0.17[1]	9.3	4.8
Sandberg bluegrass	0.58	0.18	1.08	0.57[1]	7.7	10.7
Tumblegrass	0.06	0.13	0.04	0.26	0.2	6.2
Foxtail barley	0.00	0.00	0.00	0.42	0.0	1.2
Cactus	0.83	0.06[1]	0.24	0.08	1.8	1.8
Clubmoss	9.03	0.19[1]	9.38	0.36[1]	47.9	7.0[1]
Big sagebrush	0.81	0.42[1]	0.32	0.21	2.2	4.6
Total grass	5.33	1.38[1]	5.63	3.24[1]	46.2	77.1[1]
Total forbs	10.92	0.50[1]	9.74	0.71	51.0	16.4
Total shrubs	0.85	0.65	0.36	0.28	2.7	6.5
Total cover	17.10	2.53[1]	15.72	4.22[1]	--	--
Total minus clubmoss	8.07	2.33[1]	6.35	3.86[1]	--	--

[1] Means significantly different from the check (P = 0.1).

[2] Combined average of sites 2 and 3.

accompanies the disturbance of native sod provided an additional amount of available soil nitrogen (N), which was reflected by high protein content in 1968 and increased yields in subsequent years. The increased yields had a dilution effect on the protein content, but total N uptake was considerably greater on the furrowed than on the check watershed throughout the study. Also, protein content at harvest depended on stage of maturity and increased available water in the furrows which tended to prolong the green period some years. A seasonal protein content curve for 1969 is presented in Figure 17.

The differences in P content on the check and furrowed watersheds were somewhat less than for the protein content. Three factors, working simultaneously could affect P content on the furrowed watersheds: (1) the temporary fertility effect from the mechanical disturbance of the soil and plant material; (2) the dilution effect of increased production; and (3) the increased soil water effect, which increases P uptake. Averaging the check and furrowed watersheds together, the mean and range of P content was 0.126% and 0.097-0.184%, respectively, on the saline-upland range site, and 0.140% and 0.104-0.186% respectively, on the claypan range sites.

<u>Vegetation, Plant Phenology</u>: Phenological data were collected for several plant species throughout most of the 1968-1980 study period. Data collection was intensified during the last 3 study years, 1978-1980, and only this portion of the phenological data is included here. Record of the phenological data is included in the appendix.

Observations were taken from watersheds 14, 16, 24, 26, 31, and 32, which included a furrowed and nonfurrowed watershed on each of the three study sites. Four plants of each study species (Table 16) were identified and staked for future reference on the upper and lower ends of each watershed. Where possible, the plants were selected in groups so they could be covered easily with a 4- by 6-foot wire utilization cage to exclude grazing. It was occasionally necessary to substitute observations from plants in the general area to compensate for the absence of growth or death of a staked plant.

The phenological growth stages recorded by date for the grasses were: (1) begin growth, (2) heading, (3) ripe seed, and (4) postripe seed; the growth stages for shrubs were: (1) begin growth, (2) floral bud stage, (3) late dough stage, and (4) ripe seed. The terminology and definitions of growth stages are listed in Table 17.

Growth was measured on a weekly to biweekly schedule as upstretched leaf height for grasses and average length of current year's vegetative leader growth for shrubs. Due to weather conditions and research priorities, this sampling schedule was not always possible for all study sites, which resulted in some data omissions.

Measurements of vegetative leaf heights were averaged for several plants. In some cases, the same plants were not measured each time, and the data represent an overall average for the watershed rather than an absolute measurement of specific plants. Upstretched leaf heights are an important indicator to differentiate between green-up of the previous autumn growth and actual current year's growth, especially for warm-season perennials. However,

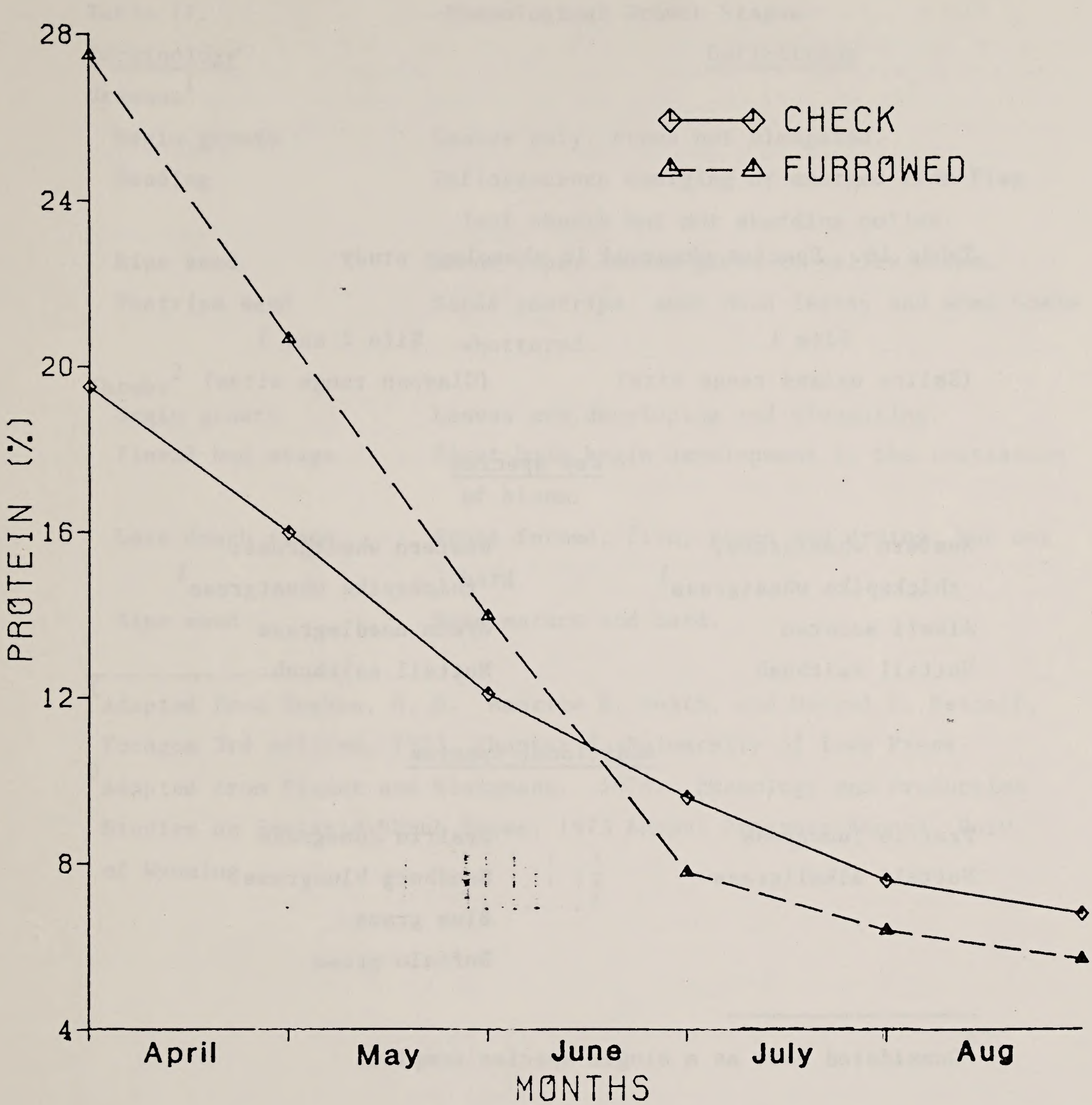

Figure 17. Seasonal changes in protein content of thickspike-western wheatgrass on a check and furrowed claypan range site, Ekalaka, Montana, 1969.

Table 16. Species observed in phenology study

Site 1 (Saline upland range site)	Site 2 and 3 (Claypan range sites)
Key species	
Western wheatgrass, thickspike wheatgrass[1]	Western wheatgrass, thickspike wheatgrass[1]
Alkali sacaton	Green needlegrass
Nuttall saltbush	Nuttall saltbush
Additional species	
Prairie junegrass	Prairie Junegrass
Nuttall alkaligrass	Sandberg bluegrass
	Blue grama
	Buffalo grass

[1] Considered here as a single species complex

Table 17. Phenological Growth Stages

Terminology	Definitions
Grasses[1]	
Begin growth	Leaves only, stems not elongated.
Heading	Inflorescence emerging or emerged from flag leaf sheath but not shedding pollen.
Ripe seed	Seeds ripe, leaves green to yellow brown.
Postripe seed	Seeds postripe, some dead leaves and some heads shattered.
Shrubs[2]	
Begin growth	Leaves are developing and elongating.
Floral bud stage	First buds begin development to the initiation of bloom.
Late dough stage	Fruit formed, firm, green and drying, but not hard.
Ripe seed	Seed mature and hard.

[1] Adapted from Hughes, H. D. Maurice E. Heath, and Darrel S. Metcalf, Forages 3rd edition, 1973, Chapter 8, University of Iowa Press.

[2] Adapted from Fisser and Kleinmann. 1974. Phenology and Production Studies on Semiarid Shrub Types, 1973 Annual Progress Report, Univ. of Wyoming.

the infrequent sampling interval of one to two weeks made it difficult to accurately determine actual date of beginning growth.

There were only a few apparent differences in the occurrence of growth stages between treatments and among sites. The observed growth stages of the western-thickspike wheatgrass complex were generally earlier on Site 1 and Site 3, than on Site 2. This may be more a species difference than a site difference. Thickspike wheatgrass, which develops earlier than western wheatgrass, is probably more predominant on Sites 1 and 3, and western wheatgrass, more predominant on Site 2.

In some cases, Nuttall saltbush appeared to be earlier, more robust, and better adapted on Site 1, than on Sites 2 and 3. It was difficult to find vigorous plants on the nonfurrowed watershed on Site 3, and on the furrowed watershed on Site 2. In 1980, the observed Nuttall saltbush plants on Site 3 did not flower. This was probably due to drought conditions.

Green needlegrass was not common to all watersheds, and its phenology was observed only on a furrowed watershed on Site 2, and on a pedestalled nonfurrowed area on Site 3. Table 18 summarizes the average dates of growth stages for all sites amd treatments.

In most cases, however, there were no measurable differences in the occurrence of the phenological growth stages between the furrowed and nonfurrowed watersheds, and among sites. This may have been due, in part, to the wide sampling interval. However, the general lack of differences indicates that contour furrowing is not likely to have a significant impact on grazing management due to changes in the phenological development of plants.

During the dry summers of 1979 and 1980, most species flowered less than under normal climatic conditions or had delayed flowering dates. Only a few western thickspike wheatgrass and blue grama plants flowered in 1979. In 1980, plant growth was restricted due to lack of soil moisture during the first part of June. However, growth resumed after rains occurred during the second week in June. Dry conditions caused most plants to slow down again around the end of July. Rains during the middle of August brought on renewed growth; blue grama had flowered very little before then, but flowered profusely after. Alkali sacaton on the saline upland site was the only species that appeared to maintain some growth during the dry periods.

No attempt was made to separate the observations in the furrowed watersheds between plants growing on the ridges and in the furrows. However, vegetation tended to remain green longer in the furrows than on the ridges and nonfurrowed areas, as would be expected with increased available water in the furrows.

Contour furrowing had a significant impact on upstretched leaf heights (Fig. 18 and 19). The increased upstretched leaf heights on the furrowed watersheds are due almost entirely to the increased water supply. This is also reflected by increased herbage yields on the furrowed watersheds.

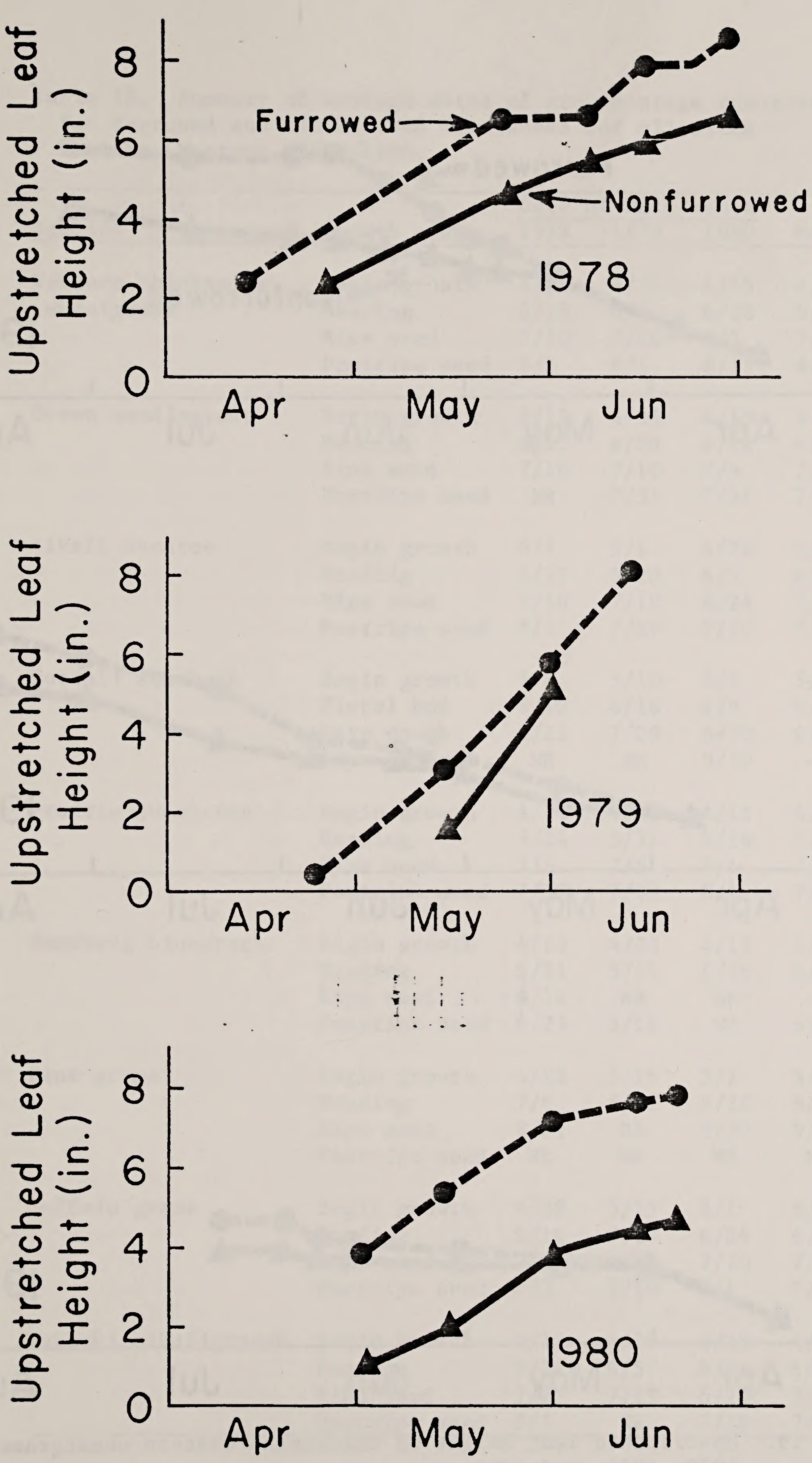

Figure 18. Upstretched leaf height of alkali sacaton in 1978, 1979, and 1980.

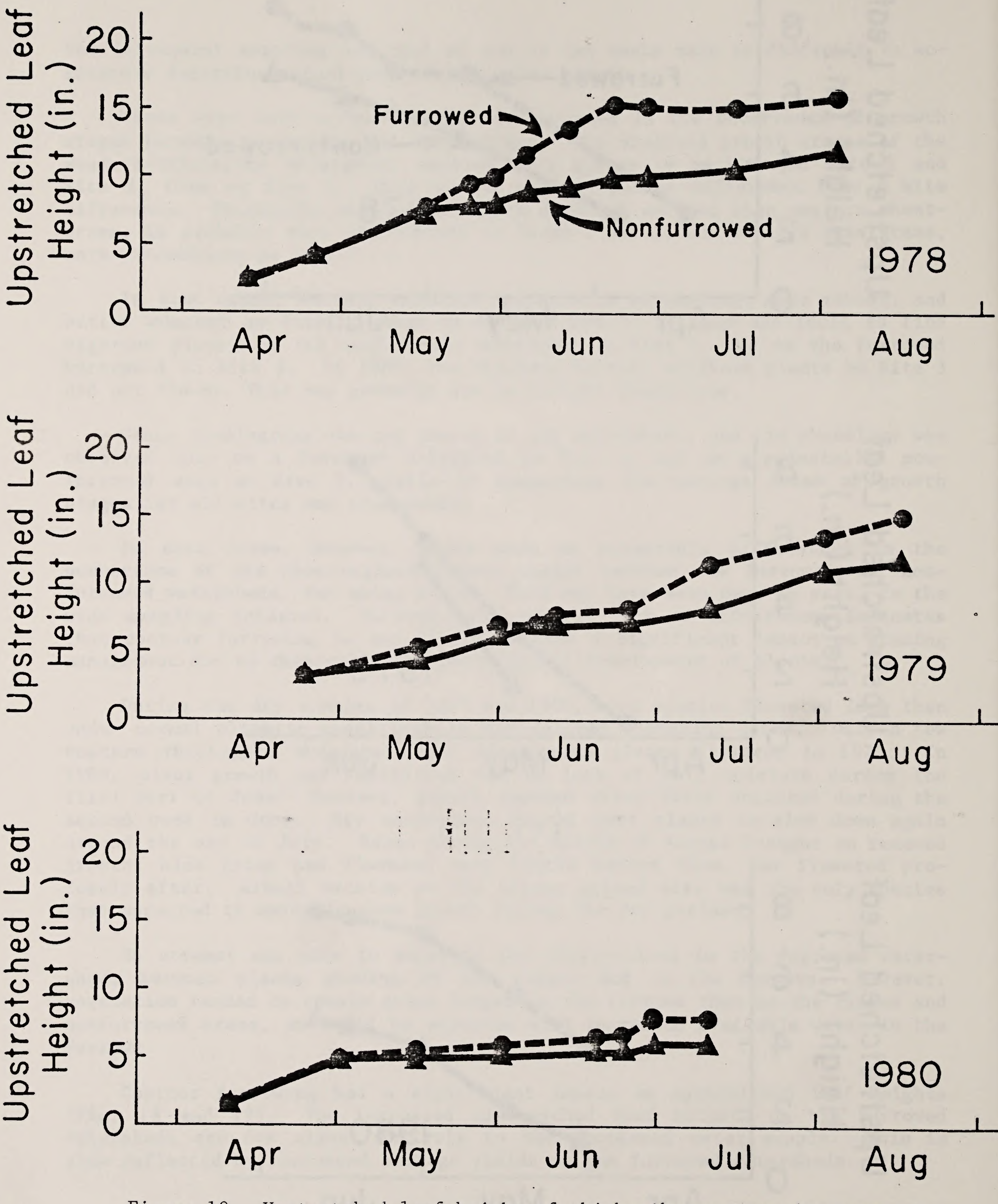

Figure 19. Upstretched leaf height of thickspike-western wheatgrass in 1978, 1979, and 1980.

Table 18. Summary of average dates of growth stage occurrence for furrowed and nonfurrowed watersheds for all sites - Ekalaka, Montana, 1978-1980.

		Date of Occurrence			
Species	Growth stage	1978	1979	1980	Mean
Western thickspike wheatgrass	Begin growth	4/12	4/24	4/15	4/17
	Heading	6/10	6/7	6/28	6/15
	Ripe seed	7/10	7/10	8/1	7/17
	Postripe seed	8/3	8/1	8/15	8/10
Green needlegrass	Begin growth	4/13	4/25	4/15	4/18
	Heading	6/15	6/26	6/22	6/21
	Ripe seed	7/10	7/10	7/6	7/12
	Postripe seed	NR	7/31	7/31	7/31
Alkali sacaton	Begin growth	5/1	5/1	4/20	4/25
	Heading	6/27	6/20	6/9	6/18
	Ripe seed	7/10	7/10	6/24	7/5
	Postripe seed	8/4	7/29	7/10	7/25
Nuttall saltbush	Begin growth	5/1	5/10	5/1	5/4
	Floral bud	6/10	6/16	6/8	6/11
	Late dough	8/22	7/29	8/30	8/14
	Ripe seed	NR	NR	9/30	--
Prairie junegrass	Begin growth	4/11	4/25	4/15	4/17
	Heading	5/24	5/31	5/29	5/28
	Ripe seed	7/5	7/6	7/1	7/4
	Postripe seed	7/30	7/30	8/1	7/31
Sandberg bluegrass	Begin growth	4/13	4/25	4/15	4/18
	Heading	5/21	5/31	6/16	6/2
	Ripe seed	6/14	NR	NR	--
	Postripe seed	6/29	6/26	NR	6/28
Blue grama	Begin growth	4/28	5/16	5/1	5/6
	Heading	7/6	8/12	8/26	8/4
	Ripe seed	8/21	NR	9/30	9/5
	Postripe seed	NR	NR	NR	NR
Buffalo grass	Begin growth	4/30	5/15	5/1	5/5
	Heading	6/14	7/1	6/24	6/23
	Ripe seed	7/13	6/26	7/10	7/6
	Postripe seed	8/3	7/10	8/1	7/25
Nuttall alkaligrass	Begin growth	4/10	4/26	4/15	4/17
	Heading	5/24	6/5	6/9	6/2
	Ripe seed	7/1	7/29	6/24	7/8
	Postripe seed	8/3	NR	7/10	7/22

Disposition of Research Facilities: Field data were collected until the end of FY 1980. In 1981, we removed all field instruments except the water measuring flumes which were left in place, enclosed by protective barbed wire fences. These flumes could not be removed without destroying their usefulness as water measuring devices. We recommend that the flumes and the experimental watersheds be left in place and that the watersheds be grazed under the same management plan as the pastures in which they are located. Leaving these facilities in place will make possible future short-term hydrologic studies to verify model parameters and furrow aging characteristics as well as periodic clipping to measure long-term vegetation response to contour furrowing and grazing. Future short-term studies using these facilities will be especially valuable because of the extensive data base available from the original studies.

Rainfall Simulator: The BLM increased the financial contribution to the agreement to partially support an ARS study to evaluate a large, portable rainfall simulator. The basic simulator design originated at Colorado State University and was later modified for field use by personnel of the U.S. Geological Survey and the BLM. The ARS followed the field design and constructed a CSU Simulator with five lines of sprinklers and five sprinklers per line. Tests were conducted at various line pressures to determine operating characteristics. Conclusions reached were:

1. This configuration provides uniform rainfall areal distribution over plots greater than 3,000 square feet in size.

2. Rainfall application rates can be varied between 1.5 inches per hour and 3.0 inches per hour by varying the line pressure between 10 and 40 psi.

3. The simulator can be operated satisfactorily when average wind velocities are seven miles per hour or less. Average wind velocities greater than seven mph disrupt the areal distribution.

4. Kinetic energy delivered at the ground surface varies from about 15 percent of the kinetic energy of natural rainfall at 3.0 inches per hour up to about 75% of the kinetic energy of natural rainfall at 1.5 inches per hour. Reasons for the difference in kinetic energy between natural and simulated rainfall are: first, the simulator produces drops smaller than natural rainfall and second, the simulated rain falls about 12 feet which is insufficient distance for the larger drops to reach terminal velocity. Drops larger than 2 mm reach less than 90 percent of terminal velocity in a 12-foot fall. These comparisons between simulated and natural rainfall are open to interpretation because of questions concerning natural rainfall characteristics. For example, do drop-size distributions for storms with the same intensity differ in different geographical areas? Also, does the drop velocity of natural rainfall compare to the velocity of water drops falling in still air in a laboratory. Additional research is needed to better define

natural conditions before reliable comparisons can be made to simulator characteristics.

5. Water requirements for the CSU simulator range from 7,000 gallons per hour at an application rate of 1.5 inches per hour to 15,000 gallons per hour.

In FY 1980 the BLM requested the ARS to investigate the development of a more water efficient rainfall simulator. The simulator that was developed had the following characteristics:

1. Pump and riser pressures can be varied to produce application rates between 1.5 inches per hour and 7.5 inches per hour.

2. Water requirements vary from 400 gallons per hour at 1.5 inches per hour application to 1,800 gallons per hour at 7.5 inches per hour application.

3. Water distribution over the plot area was not uniform. Testing individual sprinklers indicated that this was due to the location of the sprinklers with regard to the plot borders. Additional testing is needed to verify this.

4. Wind appears to have a definite influence on water distribution on the research plot. Additional testing is necessary to define wind effects.

5. Drop size distribution was poorly defined because of both the location of the sprinklers with regard to the plot borders and to the wind effects. Additional testing is needed to determine drop-size distribution in relation to sprinkler operating pressure.

The ARS and the BLM discussed a cooperative agreement for FY 1982 by which the BLM would fund about 50% of the costs of a study to complete the field evaluation and to prepare a report covering both the new simulator and the CSU simulator. However, this agreement was not reached by February 1, 1982, hence the details cannot be presented here.

CONTOUR FURROWING--TECHNIQUES, APPLICATION, AND RECOMMENDATIONS

Contour Furrowing History: Contour furrowing as a management practice on semiarid rangelands evolved from contour terraces built during the 1930's on pastures in subhumid areas of the U.S. These terraces were developed for moisture conservation and erosion control, but in practice, they did not distribute runoff water uniformly. The design was modified by making the terraces smaller and smaller and placing them closer and closer together until they became contour furrows.

Equipment: The first contour furrows were constructed with ordinary farm or construction equipment pulled by either draft animals or tractors. Equipment used included moldboard plows; listers, with and without moldboards; disk plows; road graders; and scrapers. As interest in the practice developed, special machines such as the Kansas and the Iowa Furrowers were designed which were followed by the Arcadia Model B (now designated the RM-25) contour furrower developed by the U.S. Forest Service.

The RM-25 machine constructs furrows that are about 5 feet apart, have a 20-inch top width, and are about 8 inches deep. Each furrow is made by two off-set disks that throw soil in both directions. The disks are preceded by rippers that open the soil to about 10 inches below the furrow bottom. An adjustable paddle mechanism constructs intrafurrow dams at 5- to 100-foot intervals. The furrower is also equipped with a broadcast seeder for optional seeding of introduced or native forage species during the furrowing operations. The RM-25 is an extremely sturdy and rugged machine that can be used under the most adverse soil and topographic conditions. It requires little other than routine care and maintenance. Furrow depths can be precisely controlled by adjustment of the gauging wheels. Among the disadvantages are the initial cost of about $30,000 (1980) and the draft requirements. It must be pulled by a crawler-type tractor with a drawbar horsepower of about 100. The deep ripping feature significantly increases the power required to pull the machine. These disadvantages are reflected in the estimated (1981) furrowing costs of about $50.00/acre which includes contract cost for a tractor and operator plus machine amortization, maintenance, and repair.

Another development is a lister-type furrowing machine built by Mr. Frank Sparks, a rancher near Plevna, Montana. With this machine, furrows are constructed by left- and right-throw moldboard plows that have been welded together. The machine is equipped with a double-acting hydraulic cylinder that is used to control furrow depth and provide intrafurrow dams by lifting the plows out of the ground at regular intervals. The flat-bottom furrows are about 30 inches wide and 4 inches deep. Intrafurrow dams are placed about every 20 feet. This machine is also equipped with a broadcast seeder. The lister-type furrower is less rugged and requires more frequent repairs and more judicious selection of rangeland soils and topography to be furrowed. Furrow depth is controlled by the hydraulic cylinder, which is not a positive control and results in slight variations in depth. However, the initial cost (1980) is about $5,000.00 and it can be pulled by an ordinary rubber-tired farm tractor with a drawbar horsepower of 80 or more. The estimated (1981) cost of furrowing with this machine is about $12.00 per acre.

Furrow Construction: The purpose of contour furrowing is to control runoff and erosion and to develop a more favorable environment for range forage species by increasing available soil water, by improving soil physical and chemical characteristics, and by creating a better microclimate for seed germination and plant growth. The key to success is in constructing and maintaining furrow water storage capacity. Planning for contour furrowing should consider such factors as topography, soil texture, soil water content, and season of the year. Furrowing machines can operate satisfactorily on slopes up to 30%, although they are most effective on slopes less than 20%. Contour furrows are most effective in increasing forage on soils with medium- to fine-texture and are not generally recommended on coarse-textured soils. Contour furrowing should be done when the soil is moist and friable. More energy is required to furrow when the soil is either dry and hard or wet and sticky. Also, sticky soil can adhere to the equipment and cause ineffective operation of the damming mechanism on RM-25 machines.

Specific recommendations for most effective contour furrowing are:

1. Furrows should follow the contour. Water storage capacity and furrow longevity decrease rapidly as furrow bottom slope increases. Graded furrows fail in a domino pattern because drainage from upslope failures cause failures in downslope furrows by exceeding their water storage capacity. Once started, failures accelerate erosion by concentrating runoff water in rills and small channels below the failure. We recommend that sufficient project funds be allocated to the engineering required to assure adequate control of furrow slope in order to hold failures to a minimum.

2. Furrows should have well-constructed intrafurrow dams. Water storage capacity in furrows constructed by model RM-25 machines decrease rapidly because the loose, unconsolidated material making the dams settled after only a few wetting-drying and freezing-thawing cycles. The dam settling reduced the water storage capacity from a theoretical 2.5 inches to about 1 inch within the first season or two following construction. It is better to separate furrow sections by lifting the machine out of the ground a short distance at regular intervals. This practice leaves dams of consolidated, vegetated, and undisturbed soil material that does not settle and is most resistant to erosion failure, even when surface water exceeds the water storage capacity of the furrows. We recommend this practice when using either the RM-25 or the lister-type furrowing machines.

3. Furrows should be constructed at design depth. Furrow depth is related to both the design water storage capacity and to the type of furrowing machine. Water storage capacity refers to total area contribution, furrows plus ridges, rather than to absolute capacity of the furrow. Initial capacity should be 1 to 2 inches based on design storm amount. Using the RM-25 in its usual mode, this is obtained with furrows 8 to 10 inches deep. However, if RM-25 furrow sections are separated by lifting the disks out of the ground at regular intervals, the same water storage capacity can be obtained with furrows 4 to 5 inches deep because these intrafurrow dams do not settle and reduce effective furrow capacity. With lister-type furrowing machines, furrow depth should be 3 to 4 inches deep.

4. Furrows should be properly spaced. Spacing depends on furrow geometry, and furrows should occupy 40 to 50% of the treated area. A rule of thumb for determining furrow spacing is the equation: d = KW where d is furrow spacing; K is a factor that ranges from 2.5 to 3.0; and W is the constructed furrow top width. Using a K factor of 2.5 results in a 50:50 ratio between furrows and ridges, whereas a K factor of 3.0 results in a 40:60 ratio. These ratios are different from those expected from theoretical considerations since the final effective furrow width is greater than the constructed width because furrow edges slough and round off.

5. Furrows should skip natural waterways. During field construction, it is not practical to follow contours of small, well-defined waterways. The usual practice is to furrow across small drainageways as though they were not there. This creates low spots in the furrows which fail rather quickly as the channel is reformed, usually with more bank and bottom erosion than the original because of the additional runoff contribution from the failed furrow sections. We recommend lifting the machine from the ground when crossing well-defined waterways and leaving the area undisturbed. Following this practice results in fewer furrow failures, less erosion, and the undisturbed areas can be used by livestock for bedding grounds and walkways to provide easier access to furrowed areas.

6. Furrows should be constructed in blocks. Objections to contour furrowing voiced by ranchers and other rangeland users are that it prevents vehicular access for normal ranching operations and fire control; that furrowed land is difficult for livestock to traverse; and that losses may occur when livestock, particularly sheep, bed down in the furrows. These objections can be somewhat alleviated by constructing contour furrows in blocks of about 30 acres (700 feet wide by 2,000 feet long) and separating the blocks with undisturbed areas 15 to 20 feet wide, which can be used as roadways, walkways, and bedding grounds.

7. Contour furrowing should be planned as an integral part of the range resource management. New contour furrows require 1 to 3 years deferment before vegetation is plentiful and vigorous enough to withstand grazing pressure. During this period, other areas in the management system must be protected from overuse by providing either supplemental forage from another source or by instituting a carefully controlled, temporary management system that will relieve the grazing pressure on these areas.

8. Furrows should be constructed in the fall when the soil is most apt to be moist and friable and when the over-winter snow water accumulation can be used effectively for spring and early summer growth.

Interseeding: Contour furrowing can be seeded with either native or introduced vegetation although seed germination and seedling establishment in furrow bottoms is sometimes restricted because the subsoil exposed is low in fertility or high in clay and salt. Under these conditions, it may take several years before soil characteristics in the furrow bottoms are sufficiently ameliorated so that the soil can support either seeded species or invasion by indigenous species. This is more apt to occur in furrows constructed with the RM-25 machine that in shallower furrows. Near Ekalaka,

nearly 10 years elapsed before complete revegetation occurred in furrows constructed in fine-textured soils by a RM-25 furrower. Many desirable native species as well as introduced species such as crested wheatgrass. Russian wildrye, alfalfa, and biennial yellow sweetclover respond well when seeded in contour furrowing in eastern Montana. Alfalfa and sweetclover are particularly beneficial, not only for forage, but also for the nitrogen supplied by these legumes to the usually nitrogen-deficient rangelands.

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